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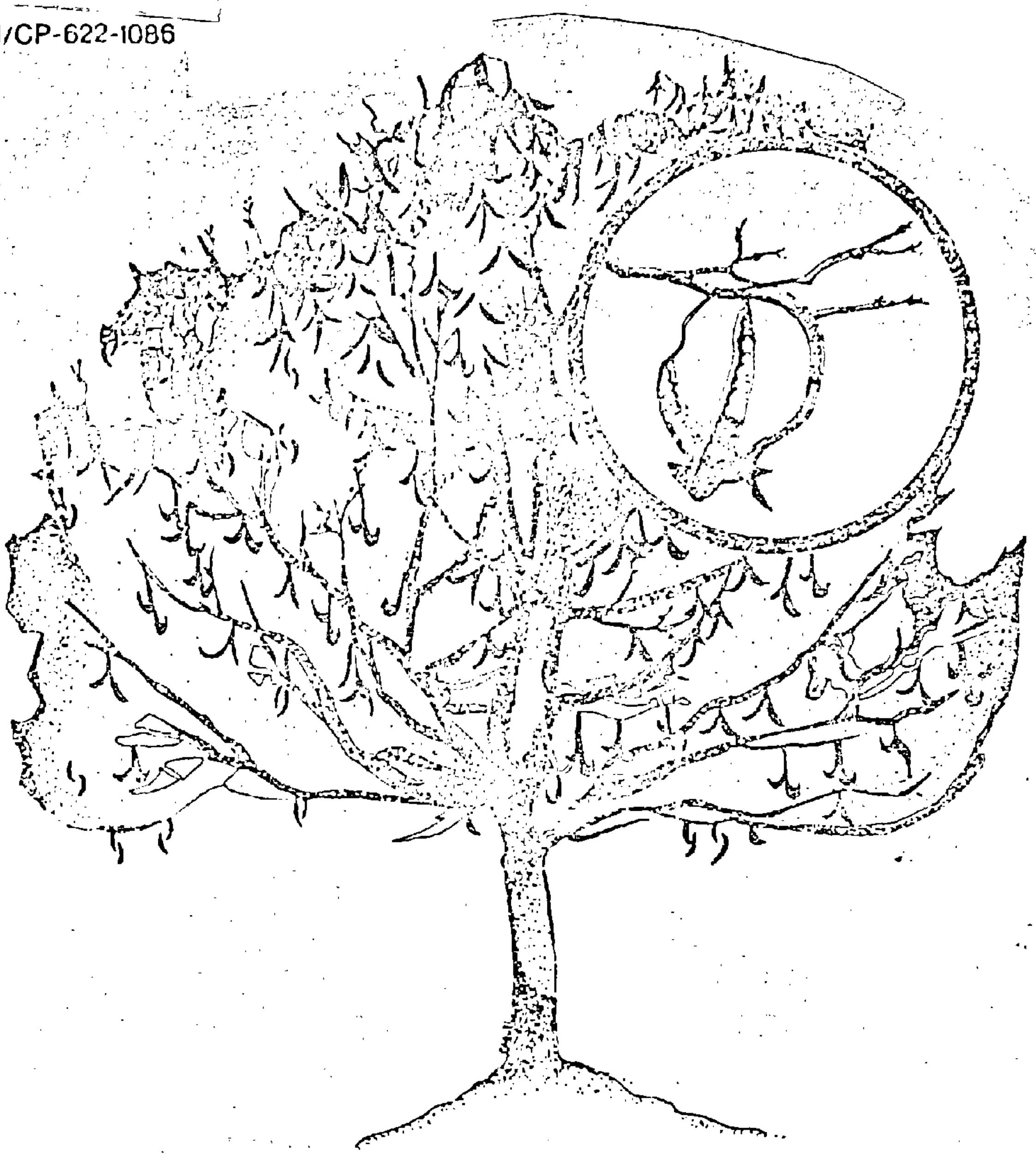

Tree Crops for Energy Co-Production on Farms

November 12 - 14, 1980

YMCA of the Rockies

Estes Park, Colorado

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TREE CROPS FOR ENERGY CO-PRODUCTION ON FARMS

NOVEMBER 12 - 14, 1980
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DEDICATION

These Proceedings are Dedicated
To the Memory of
J. RUSSELL SMITH

who through his writing of "Tree Crops - A Permanent Agriculture" inspired many of the participants in this workshop and kept interest in Tree Crops alive. The impending demands on the land from biomass for energy make his message all the more urgent today, 50 years after his first edition appeared.

"A field that is washed away is gone for ages. Hence the Old saying, 'After the man the desert.'"

J. Russell Smith

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*Indicates Presenter
**Read by G. Williams

TREE CROPS FOR ENERGY CO-PRODUCTION ON FARMS

Preface

The recent resurgence (Ref. 1) of National interest in fuel alcohol production from fermentation of agricultural crops, primarily grains, has brought with it a heightened concern for the ecological and policy implications of a perceived "food vs fuel" (2,3,4,5,6) conflict and of the conversion of additional land to grain production.

These questions are part of a broader concern about the way we produce biomass, whether for food, forage, or fuel (7,8,9,10,11,12,13,14) in terms of soil and nutrient loss, ground water depletion and non-renewable energy input. One answer may be to use fermentable substrates from lignocellulosic material such as wood, grasses, or crop residues for alcohol production, and this is a major thrust of the current National Alcohol Fuels R&D program.

A second heretofore largely unrecognized approach would employ tree crops* that, for example, contain large amounts of readily fermentable carbohydrates such as sugar. Such tree crops are viewed as a possible perennial component of a diversified agricultural system at the farm level. The idea is that some trees produce an annual crop such as pods, seeds, or fruit that contains the fermentable substrate. This crop can be used for low technology energy production on a local basis, while the trees continued accumulating wood and contributed the other benefits that trees provide.

Tree crops have many advantages over row crops. These include the potential for high yields from land unsuitable for cultivation; adaptability to semi-arid conditions and poor soils; sustainable production without soil loss; low energy input and secondary benefits such as retaining rainfall, controlling wind, and providing wildlife habitat. As an illustration, one possibility discussed by several speakers is the use of the honey locust tree in pasture land and more generally on land unsuited for intensive cultivation. At proper density, the canopy does not absorb enough sunlight to seriously decrease grass production, yet the tree produces a large amount of pods suitable for animal forage or energy. The sugar content of pods ranges up to 40%. If the sugar were fermented to alcohol, the farmer

*We use "tree-crops" in the historic sense popularized in J. Russell Smith's classic book (7). Synonyms are "Agroforestry" and "Agri-Silviculture". "Tree crops" of pods, fruits, nuts, etc. are to be contrasted with crops of trees utilized in woodlots or silviculture energy plantations, where wood is the primary product.

could use his pastures to produce fuel and still have the mash (a good protein source) left over for feed to supplement the pasture grass.

To explore the implications of tree crops for energy production on farms, a SERI task force consisting of Donald Hertzmark, Robert Inman, Thomas Milne, Michael Seibert, and Carl Strojan was formed in the Spring of 1980.

The first activity was to organize this specialists workshop to provide an initial assessment of the technical, economic, social, and ecological feasibilities of energy co-production from various tree-crop systems that have been proposed. The workshop, consisting of 16 speakers and 36 participants, was held at the YMCA of the Rockies in Estes Park, Colorado from November 12-14, 1980.

This volume contains the papers presented at the workshop, and a summary of the last day's discussion about future research, development and demonstration recommendations. The appendix contains a computer-search bibliography on tree-crops that serves to supplement the references listed by each of the contributors.

The workshop produced a lively dialogue among attendees on matters of energy and sustainable agriculture. It is our hope that the publication and wide distribution of these proceedings will enlarge the dialogue and lead to the serious consideration of an adequately funded RD&D program to explore and implement diversified applications of tree crops for energy on farms and in rural settings. We welcome correspondence with interested readers.

Thomas A. Milne

Thomas A. Milne,
Workshop Chairman.
Donald Hertzmark; Robert Inman, Michael Seibert,
and Carl Strojan, SERI Tree Crop Task Force

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Session I

Potential Tree Crops Species
Chairman — Michael Seibert
Photobiology Group, SERI

"We should carefully scrutinize types of agriculture in relation to environment. Agriculture America should scientifically test the plant kingdom in relation to potential human use and do it as carefully and patiently as industrial America has tested cement."

". . . the crop-yielding tree offers the best medium for extending agriculture to hills, to steep places, to rocky places, and to the lands where rainfall is deficient. New trees yielding annual crops need to be created for use on these four types of land."

J. Russell Smith

TREE CROPS FOR ENERGY PRODUCTION IN APPALACHIA

Gregory Williams
International Tree Crops Institute U.S.A., Inc.
Appalachian Regional Office
Gravel Switch, Kentucky

ABSTRACT

Fruits of some trees and shrubs may be attractive alternatives to grain as feedstocks for fuel alcohol production in Appalachia. Among several candidate species of woody perennials, *Gleditsia triacanthos* L. (honeylocust) and *Diospyros virginiana* L. (persimmon) have the greatest potentials for high annual yields of fermentable carbohydrates with low economic and artificial energy input requirements. Scenarios developed for propagation, planting, maintenance, harvesting, storage, and processing of energy producing tree crops reveal needs for research and demonstration trials before detailed economic and net energy analyses can be made.

INTRODUCTION

Much of the Appalachian Region, which officially includes 397 counties in 13 states (New York, Pennsylvania, Maryland, West Virginia, Ohio, Kentucky, Virginia, North Carolina, Tennessee, South Carolina, Georgia, Alabama, and Mississippi), is adjacent to large urban markets for liquid fuels (Pickard, 1980). Farm-produced fuel alcohol might improve the Appalachian agricultural economy while reducing the dependency on imported petroleum of the East, but opportunities for biomass cropping are limited by topography. Most of the Region is hilly or mountainous; for example, two-thirds of West Virginia has slopes of 20% or greater (Colyer, 1976). Over 50% of the land area in the Region has been classified by the Soil Conservation Service as "unsuited to normal cropping" (Coltrane and Baum, 1965). The rugged topography has slowed trends toward large agribusiness operations: average farm size in 1974 was less than 150 acres, and more than 80% of all farms had annual sales under $20,000 (McArthur, 1979). Many Appalachian farmers, faced with low farm income, have turned to outside employment.

Current fuel alcohol technology and economics favor ethanol production from starch or sugar over ethanol or methanol production from cellulose (Paul, 1979). Corn, sorghum, small grains, and potatoes (conventional sources of starch and sugar) are highly soil erosive on hill lands unless capital-intensive reduced-tillage techniques are used (Phillips, et al., 1980). Increasing energy prices will tempt Appalachian farmers, most of whom cannot afford reduced-tillage equipment, to plow their slopes for alcohol production. Trees and grass are better suited to Appalachian topography, but these perennial crops are regarded conventionally as biomass sources of cellulose only.

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Some woody perennials suited to Appalachian conditions yield annual crops of high (non-cellulosic) carbohydrate content fruits (Table 1). These plants are inherently soil conserving, since they do not require annual seedbed preparation and cultivation. Most of these plants have been given little attention in the past, except as ornamentals. Only a few are grown commercially for their fruits. This paper is an initial attempt to evaluate some of these tree crops (including shrubs and vines) for ethanol production in Appalachia.

CANDIDATE TREE CROPS FOR ETHANOL PRODUCTION

Reliable data on fruit yields are sparse for many of the species listed in Table 1; fermentable carbohydrate composition data for the fruits of some species listed in Table 1 are lacking. Table 2 presents estimated ethanol yields for those species with yield and composition data given in books and articles in the I. T. C. I. U. S. A. Appalachian Regional library. The estimated ethanol yields are based on 85% conversion efficiency of starches and sugars, using the methods of Jacobs and Newton, 1938, and should be treated as order-of-magnitude values subject to revision on the basis of additional information. Actual ethanol yields will depend on many factors, such as cultivars, age of plants, site conditions, rainfall, etc.; estimated yields assume mature plants, good site conditions, rainfall adequate, and generally, use of selected high-yielding cultivars. Estimated yields noted as "max." are based on estimated maximum (no "limiting factors") fruit yields given by Westwood (1979, p. 228), and much lower yields can be expected on average.

Fruit (and hence, ethanol) yields from tree crops are generally higher with increased maintenance, such as pruning or spraying for insect and disease control, but some species, as noted in Table 2, require little maintenance for high yields. Some species bear when young, others (notably oaks and hickories) may not bear heavily until 30 or 40 years old. A few species are not hardy in the northern parts of the Appalachian Region. And a few species bloom early in the spring; their yields are subject to blossom damage by late frosts, which are prevalent in Appalachia.

Coproduction of animal feed can be an important economic factor in fuel alcohol production; the feeding value of stillage from most tree crop feedstocks will be lower than that of stillage from corn, because corn has a higher protein content than most of the fruits. However, the feeding value of stillage from honeylocust and walnut fruits should be higher than that of corn stillage.

Another consideration is fruit perishability. The nuts and honeylocust pods store indefinitely, but the other fruits listed in Table 2 do not store well. Ethanol production from the latter must be seasonal, and may be uneconomical.

Table 3 ranks the species of Table 2 according to estimated ethanol yields and maintenance requirements. Group 1 (high feasibility) species deserve further consideration as promising fuel alcohol sources requiring low maintenance; Group 2 (medium feasibility)

species require high artificial energy and labor inputs for high yields; Group 3 (low feasibility) species show little promise for ethanol production. Honeylocust, Oriental persimmon, and persimmon have the highest estimated ethanol yields of the Group 1 species. The Oriental persimmon is not hardy in much of Appalachia, and will not be discussed further in this paper. The honeylocust and (native American) persimmon are examined below as representative ethanol-producing tree crops.

SCENARIOS FOR TREE CROP ETHANOL PRODUCTION

For Appalachia, ethanol from corn is the appropriate standard for evaluating ethanol from tree crops on the basis of both economic and net energy analyses. An 80 bushels/acre corn crop (optimistic for hill lands) yields about 210 gallons of ethanol/acre (Jacobs and Newton, 1938). In 1979, the average corn production cost in the Southeast was $2.33/bushel (Anonymous, 1980), or about $.90/gallon of ethanol (fermenting and distilling costs not included). Artificial energy inputs for corn production have been estimated at about 130,000 Btu/bushel, or about 50,000 Btu/gallon of ethanol (Solar Energy Research Institute, 1980).

Tree crop production costs and energy inputs are difficult to estimate. Published figures are for high-maintenance tree crops only. For example, dwarf apples in Kentucky have been estimated to require about $2000/acre for a yield of 40,000 pounds/acre (Allen, et al., 1978). If production costs for ethanol tree crops cannot be lower than this, even the highest yielding honeylocusts would produce $2/gallon ethanol, not counting fermenting and distilling costs. Much of the production costs for apples as food are due to pruning and quality requirements (freedom from blemishes due to insects, diseases, and physical damage); costs of pesticides and labor for hand picking and pruning amount to $1200/acre, so if these costs were cut by 5/6, total production costs per gallon of ethanol would be halved. Energy inputs for (nonirrigated) U.S. apple production have been estimated at about 31 million Btu/acre (about 23 million Btu/acre without insecticides and fungicides) (Pimentel and Pimentel, 1979). For the highest yielding honeylocusts, this amounts to about 32,000 Btu/gallon of ethanol (without pesticides, about 24,000 Btu/gallon of ethanol).

These estimates do not include some significant externalities which might favor tree crops over corn. Most important, of course, is reduced soil erosion with the former. Drought-resistant tree crops can be planted where corn cannot, thus "growing fuel" on marginal lands, and saving the prime lands for food production. Also, tree crops accumulate wood biomass for future harvest as firewood or timber. And, if tree crops are planted in pastures or meadows, grass production makes a second crop from each field.

Scenarios for propagation, planting, maintenance, harvesting, storage, and processing of energy producing tree crops are developed below for honeylocust and persimmon. More cultural information is available on these species than on most of the others in Group 1.

Honeylocust can be propagated easily by budding, and young trees transplant well, so orchards of high-yielding cultivars could be established at relatively low cost. Grass grows well under the lacy honeylocust foliage; about 40 trees/acre seems appropriate. Even young honeylocusts are drought-tolerant, and suited to shallow soils. The trees must be fertilized (including nitrogen), and the soil should be approximately neutral. Demonstration trials are needed to determine the extent of insect (particularly mimosa webworm) problems in large plantings. Weed controls can be mulches or herbicides. Blooming is late, after frosts. Apparently, no pruning is necessary for high pod yields, but research may show that some pruning reduces alternate bearing. Harvesting is problematic, because the pods tend to fall gradually over the winter; mechanical and chemical techniques for inducing quick pod fall need to be investigated. Once the pods are on the ground, they can be raked up easily. When the pods are stored, care must be taken to avoid self-heating, and, if the seeds are valued, fumigation is necessary to destroy weevils. The pods can be crushed with a hammermill. More information on honeylocust can be found in Detwiler, 1947, and Smith, 1950.

Vegetative propagation of persimmon is also easy, but transplanting is difficult. Techniques for foolproof transplanting should be developed; these will probably involve undercutting of the root systems while in the nursery. The trees grow rather slowly, with compact form, so about 80 trees/acre is a reasonable spacing. Wild trees are capable of yielding heavily on very poor, acidic, droughty sites; nevertheless, fertilization will probably aid production. Persimmons tend to self-prune, and the better cultivars show little or no tendency to alternate bear; they flower late, and are seldom hurt by late frosts. Insect pests and disease problems are minor, with the exception of persimmon wilt in Tennessee and possibly Oklahoma; the wilt disease is not present in Appalachia currently, nor does it appear threatening to Appalachian persimmons (Toole and Lightle, 1960). The small fruit size could make harvesting difficult. Research on harvesting techniques is needed: the ripening period extends over several weeks, but simultaneous ripening can be induced by chemical sprays (Griffith and Griffith, 1975); shaker-catcher devices may be needed for fruit collection. The fruits are rather fragile, and should be processed soon after collection. More information on persimmon is given by Troop and Hadley, 1896, Fletcher, 1942, and McDaniel, 1973.

Additional research will be necessary before ethanol production from tree crops can be optimized, and demonstration trials are required for detailed economic and net energy analyses to be made. Theoretically, tree crops for energy production in Appalachia appear promising; practically, their viability must be judged experimentally.

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TABLE 1. Woody perennials suited to Appalachian conditions which produce high (non-cellulosic) carbohydrate content fruits

Scientific Name	Common Name	Plant Type	Fruit Type	Fruit Size
Actinidia arguta Miq.	tara	vine	berry	3/4"
Aesculus spp. L.	buckeyes	tree	capsule	1-3"
Amelanchier spp. Med.	serviceberries	shrub or small tree	pome	1/4-1/2"
Arctostaphylos uva-ursi (L.) Spreng.	bearberry	shrub	drupe	1/4-1/2"
Aronia spp. Med.	chokeberries	shrub	pome	1/4-1/2"
Asimina triloba (L.) Dunal.	pawpaw	shrub or small tree	berry	2-7"
Berberis spp. L.	barberries	shrub	berry	1/4-1/2"
Callicarpa americana L.	American beautyberry	shrub	drupe	0.03"
Carya spp. Nutt.	hickories	tree	nut	3/4-1 1/2"
Castanea spp. Mill.	chestnuts	tree	nut	1/2-1 1/2"
Celtis spp. L.	hackberries	tree	drupe	1/4"
Chaenomeles lagenaria Koid.	Japanese quince	shrub	pome	1 1/2-2"
Chionanthus virginicus L.	fringetree	shrub or small tree	drupe	3/4"
Cornus spp. L.	dogwoods	shrub or small tree	drupe	1/8-1/4"
Corylus spp. L.	hazels	shrub	nut	1/2"
Crataegus spp. L.	hawthorns	shrub or small tree	pome	1/4-1/2"
Cudrania tricuspidata (Carr.) Bar.	che	small tree	drupe aggregate	1-1 1/2"

TABLE 1. (continued)

Scientific Name	Common Name	Plant Type	Fruit Type	Fruit Size
Cydonia oblonga Mill.	quince	shrub or small tree	pome	ca. 3"
Diospyros spp. L.	persimmons	tree	berry	1/2-4"
Elaeagnus spp. L.	elaeagnus	shrub or tree	drupe	1/4-3/4"
Fagus spp. L.	beeches	tree	nut	1/2-1"
Gaultheria spp. L.	wintergreens	shrub	pseudoberry	0.1-0.4"
Gaylussacia spp. L.	huckleberries	shrub	drupe	1/4-1/2"
Ginkgo biloba L.	ginkgo	tree	drupe	1"
Gleditsia triacanthos L.	honeylocust	tree	pod	3-20" long
Gymnocladus dioicus (L.) K. Koch	Kentucky coffeetree	tree	pod	6-10" long
Ilex spp. L.	hollies	shrub or tree	drupe	1/4-1/2"
Juglans spp. L.	walnuts	tree	nut	1-1 1/2"
Juniperus virginiana L.	eastern redcedar	tree	berry	1/8"
Ligustrum spp. L.	privets	shrub	drupe	1/3-1/2"
Lindera benzoin L. Blume	spicebush	shrub	drupe	1/2"
Lonicera spp. L.	honeysuckle	shrub or vine	berry	1/4"
Maclura pomifera (Raf.) Schneid.	osage-orange	small tree	drupe aggregate	4-5"
Malus spp. Mill.	apples	tree	pome	1/2-4"

TABLE 1. (continued)

Scientific Name	Common Name	Plant Type	Fruit Type	Fruit Size
Mespilus germanica L.	medlar	small tree	pome	1-2 1/2"
Mitchella repens L.	partridge-berry	vine	berry	1/4"
Morus spp. L.	mulberries	tree	drupe aggregate	1/2-1"
Myrica spp. L.	bayberries	shrub or small tree	drupe	1/8-1/6"
Nemopanthus mucronata (L.) Trel.	mountain-holly	shrub	drupe	1/4-1/3"
Parthenocissus spp. Planch.	creepers	vine	berry	1/4"
Pinus spp. L.	pines	tree	cone	seeds, 1/8-1/2"
Prunus spp. L.	cherries, plums and peaches	tree	drupe	1/2-3"
Pyrus communis L.	pear	tree	pome	1 1/2-4"
Quercus spp. L.	oaks	tree	acorn	1/2-1 1/2"
Rhamnus spp. L.	buckthorns	shrub or small tree	drupe	1/4-3/8"
Rhus spp. L.	sumacs	shrub or tree	drupe	0.12-0.16"
Ribes spp. L.	currants, gooseberries	shrub	berry	1/4-1"
Rosa spp. L.	roses	shrub	hip	1/8-1/2"
Rubus spp. L.	blackberries, raspberries	shrub or vine	drupe aggregate	1/2"
Sambucus spp. L.	elders	shrub or small tree	drupe	1/8-1/4"

TABLE 1. (continued)

Scientific Name	Common Name	Plant Type	Fruit Type	Fruit Size
Sassafras albidum (Nutt.) Nees	sassafras	tree	drupe	1/3-1/2"
Shepherdia spp. Nutt.	buffaloberry	shrub	berry	1/8-1/4"
Smilax spp. L.	greenbriers	vine	berry	1/4"
Solanum dulcamara L.	bitter nightshade	vine	berry	1/2"
Sorbus spp. L.	mountain-ash	shrub or tree	pome	1/4-1/2"
Symphoricarpos spp. Duham.	snowberries	shrub	berry	1/4"
Vaccinium spp. L.	blueberries, cranberries	shrub	berry	1/4-1"
Viburnum spp. L.	viburnums	shrub or small tree	drupe	1/4-1/2"
Vitis spp. L.	grapes	vine	berry	1/3-1"
Ziziphus jujuba Mill.	jujube	tree	drupe	1-2"

TABLE 2. Estimated ethanol production from selected woody perennials

Scientific Name	Common Name	Est. Ethanol (Gal. /Acre)	Notes
Amelanchier spp. Med.	serviceberries	30-130	low maintenance; precocious
Asimina triloba (L.) Dunal.	pawpaw	20-40	difficult to establish, but low maintenance
Carya illinoensis (Wang.) K. Koch	pecan	2-3	slow to bear; tends to alternate-bear; needs long growing season to mature nuts
Carya ovata (Mill.) K. Koch	shagbark hickory	5-8	slow to bear
Castanea mollissima Bl.	Chinese chestnut	3-50	precocious; blooms fairly early (may be subject to late frosts)
Cornus spp. L.	dogwoods	ca. 7	low maintenance
Corylus spp. L.	hazels	3-30	filbert blight; high protein
Crataegus spp. L.	hawthorns	ca. 110	low maintenance
Diospyros kaki L.	Oriental persimmon	80-640	hardiness problems; blooms early (subject to late frosts); difficult to establish
Diospyros virginiana L.	persimmon	140-360	wilt disease, TN and south; low maintenance; difficult to establish
Fagus grandifolia Ehrh.	American beech	ca. 6	
Gleditsia triacanthos L.	honeylocust	160-960	tends to alternate-bear; low maintenance; mimosa webworm in some areas; high protein
Ilex spp. L.	hollies	ca. 7	
Juglans nigra L.	Eastern black walnut	2-4	tends to alternate-bear; high protein

TABLE 2. (continued)

Scientific Name	Common Name	Est. Ethanol (Gal. /Acre)	Notes
Juglans regia L.	Persian walnut	5-40	blooms early (subject to late frosts); high protein
Malus pumila Mill.	apple	40-670(max.)	high maintenance
Morus spp. L.	mulberries	ca. 100 (or more?)	low maintenancé; birds eat fruit
Prunus americana Marsh.	wild plum	ca. 2	blooms early (subject to late frosts)
Prunus avium L.	sweet cherry	190(max.)	high maintenance; birds eat fruit
Prunus cerasus L.	sour cherry	130(max.)	high maintenance; birds eat fruit
Prunus domestica L.	plum	270(max.)	high maintenance
Prunus persica (L.) Batsch.	peach	350(max.)	high maintenance; blooms early (subject to late frosts)
Pyrus communis L.	pear	530(max.)	high maintenance
Quercus spp. L.	oaks (most)	20(max.)	extremely variable bearing; slow to bear
Quercus acutissima Carr.	sawtooth oak	ca. 70 at 10 yrs. old	annual bearing; precocious; low maintenance
Ribes spp. L.	currants, gooseberries	3-40	low maintenance; host for white pine blister rust
Rubus spp. L.	blackberries, raspberries	210(max.)	low maintenance(?)
Sambucus canadensis L.	elderberry	40-110	low maintenance; precocious
Vaccinium corymbosum L.	blueberry	30-160	requires acid soil

TABLE 2. (continued)

Scientific Name	Common Name	Est. Ethanol (Gal. /Acre)	Notes
Vaccinium macrocarpon Ait.	cranberry	70-350	requires bogs; high maintenance
Viburnum trilobum Marsh.	highbush cranberry	60-280	low maintenance; precocious
Vitis spp. L.	grapes	60-240	high maintenance
Ziziphus jujuba Mill.	jujube	ca. 150	low maintenance

TABLE 3. Feasibility ranking of selected woody perennials for ethanol production

Group 1, high feasibility (high yields, low maintenance)	Group 2, medium feasibility (high yields, high maintenance)	Group 3, low feasibility (low yields)
blackberries, raspberries	apple	American beech
blueberry	cranberry	Chinese chestnut
elderberry	grapes	currants, gooseberries
hawthorns	peach	dogwoods
highbush cranberry	pear	Eastern black walnut
honeylocust	plum	hazels
jujube	sour cherry	hollies
mulberries	sweet cherry	oaks
Oriental persimmon		pawpaw
persimmon		pecan
sawtooth oak		Persian walnut
serviceberries		shagbark hickory
		wild plum

A CASE STUDY OF HONEYLOCUST IN THE TENNESSEE VALLEY REGION

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Abstract

Sugar content of the pods, high yields, and conservation values have stimulated interest in honeylocust for years and raised prospects of plantations to provide livestock feed, sugar, or alcohol. Early interest by the Tennessee Valley Authority brought the species into its tree crops development project in 1934. This paper deals primarily with results from TVA studies dealing with selection and clonal development, flowering and controlled pollination, vegetative propagation, development of thornless clones, growth and yield, chemical analyses, feed value, and effects on pasture grasses. Particularly notable were selection of sweet pod cultivars, 'Millwood' and 'Calhoun,' and successful propagation of thornless clones. These results and observed traits of honeylocust are considered as to potential impact on use of honeylocust for energy production.

Honeylocust (*Gleditsia triacanthos* L.) is native to the central United States and has naturalized east of the Appalachian Mountains from South Carolina to New England (Little 1979). Also, the species has been planted in many areas of the United States with generally successful results. It is being grown now in countries overseas such as South Africa, India, and New Zealand.

Major attention first focused on the cropping possibilities of honeylocust when J. R. Smith (1929) described the use of different tree species in developing a permanent agricultural system on marginal and eroded farmlands. J. W. Hershey (1935) included honeylocust in TVA's

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early tree crops program for improving eroded lands in the Tennessee Valley. An extensive collection of correspondence and information relating to honeylocust was compiled by Detwiler (1947), but following World War II interest in honeylocust gradually waned. A resurgence of interest in the species was stimulated by requests from foreign countries for seed and information (Santamour 1978) and demands from young farmers attempting to develop tree crops for submarginal farmland (Tozer 1980).

A national need to reduce dependence on petroleum has initiated the search for alternate sources of liquid fuels. In the review of crops suitable for production of alcohol, honeylocust was listed as a potential candidate because it offered perennial production of fruit pods with high sugar content. To adequately consider the potential of honeylocust as an energy source, it is necessary to review the results and implications from earlier investigations. The following summary is based primarily on studies carried out in the Tennessee Valley region.

Selection of Superior Native Trees

Search for the best honeylocust trees was initiated by J. Russell Smith in the 1920's, when he actively promoted several contests sponsored by the American Genetic Association. Publicized in the Journal of Heredity, the contests drew entries from 36 States (Harrel 1937). A wide variation in pod characteristics was noted, and generally the best pods came from trees in the South.

In the 1930's selection of superior trees was the initial effort in TVA's tree crops program. Its contest to locate the best honeylocust specimens in the eastern United States was held in the fall of 1934. News releases were sent to county agents throughout the Tennessee Valley and also to farm periodicals and newspapers. For example, the Southern Agriculturist (September 1934) alerted those having "fine specimens of honey locusts, those bearing good crops of large, plump, and sweet pods" to contact TVA. Although interest was broad, only 17 entries were actually submitted for judging. Contest winners, based primarily on sugar content of the pods, included:

	First Prize	Second Prize	Third Prize
Tree owner	L. H. Calhoun	J. A. Torbett	Dave Millwood
Tree location	Etowah Co., AL	Rhea Co., TN	Haywood Co., NC
Total sugar content	36.45 percent	34.3 percent	31.2 percent
Pod length	14 inches	13.5 inches	15 inches
Number pods per pound	17	21	13

Emphasis in propagation and testing centered around the 'Calhoun' and 'Millwood,' which were relatively thornless, while the 'Torbett,' a very thorny tree with smaller pods, was delegated to a lower priority. The search for better trees was continued through the late 1930's by TVA, and in 1939 J. Russell Smith sponsored a final contest, but no

trees showing overall superiority were discovered. Some found with specific traits such as clustering of fruit or unusually thick pods, were propagated on a limited basis for use in future breeding.

A rangewide collection of honeylocust seed conducted by Dr. James Hanover of Michigan State University in 1979 is likely to provide new information on variation in the species and may lead to development of new selections.

Presently the 'Millwood' and 'Calhoun' varieties are considered almost exclusively in applications where pods of high sugar content are desirable. However, TVA still retains 14 other named clones from early studies (Appendix I). Some may have merit for use in breeding programs, while others are of limited value.

Flowering and Controlled Pollination

The flowering of honeylocust is described botanically as polygamo-dioecious; that is, it generally has staminate (male) flowers on one tree and pistillate (female) flowers on another tree but the trees are not 100 percent pure in this sex division. Moore (1948) reported a wide variation in flowering among honeylocust trees. J. C. McDaniel noted that in his extensive observations he never saw pollen produced on pistillate trees, while nearly all staminate trees had a few female flowers (Moore 1948). He recommended that, unless pod-bearing clones were developed having pollen-producing capability, honeylocust plantings should include some staminate trees to improve pollination.

From TVA studies of controlled pollination during 1938 and 1939, it was determined that standard crossing procedures of bagging the immature pistillate flowers and introducing pollen were successful. Male-female incompatibility was not found in the 16 crosses attempted using pistillate clones 'Calhoun' and 'Brown.' Viable seed resulted from 9 crosses; seed from the others were lost due to mechanical damage or insect and disease attack on the maturing fruit pods. No records were made of the performance of progeny from the crosses.

Controlled breeding of selected honeylocust is feasible and should be used in programs to upgrade and combine traits from selections.

Vegetative Propagation of Honeylocust

Propagation of sweet pod selections of honeylocust has been done primarily by modified cleft and whip, or tongue, grafting and inverted-T budding. These methods have been successful, but they are costly and labor-intensive and cause problems of sprouts and suckers.

An early study by TVA (Kline 1938) showed the potential of using root cuttings to more efficiently produce planting stock of the selections. Kline found that 96 percent of 5-inch root cuttings, 0.25- to 0.75-inch diameter, from two-year-old seedlings survived and grew into usable

plants in one year. Each of the plants provided an average of 10 root cuttings that could be used for additional nursery propagation.

The problem was that selections like 'Millwood' and 'Calhoun' were grafted and their root material was not available. TVA provided stem cuttings and grafted trees of the two clones to the USDA National Observational Nursery in Beltsville, Maryland, for development of rooted cuttings. Using these materials Stoutemyer et al. (1944) tried hardwood and softwood cuttings under greenhouse and nursery conditions using root-inducing hormones and had some success. Greenhouse rooting was reported to be slow. Cuttings set in the nursery in the fall were a total failure, while those set in the spring averaged 20 percent rooting. Softwood cuttings taken from branchwood of mature trees did not root, while cuttings from stump and root sprouts rooted easily in the greenhouse. Stoutemyer reported difficulty in getting renewed growth of cuttings after rooting in the greenhouse. It was concluded that root cuttings were most promising for large-scale propagation of honeylocust selections.

A number of rooted cuttings of 'Calhoun' and 'Millwood' were returned to TVA to develop production techniques using root cuttings, but the project was interrupted by World War II and never completed.

Propagation of Thornless Clones

Native honeylocusts on farms or in the forest are often considered a nuisance or an outright danger to man and livestock because of the thorns. Some are needlelike, 1-4 inches long, while others are multibranched, up to 12-18 inches long, and most are stout enough to cause serious injury to cattle or puncture tractor tires.

Although thornless trees are known to occur, they are rare in the Tennessee Valley and all of the selected honeylocusts had at least a slight degree of thorniness. The propagation of thornless clonal plants for pasture use was a necessity.

Observations in propagation of various clones by TVA showed that scions taken from thornless portions of trees appeared to produce grafted stock that remained thornless. Tests were initiated in 1939 and 1940 to evaluate scionwood selection and develop thornless propagation techniques (Chase 1947). In the comprehensive 1940 test, scions from thorny wood produced 77 thorny and 14 thornless trees, partly thorny scionwood produced 99 thorny and 120 thornless trees, and thornless scionwood produced 113 thornless and 5 thorny trees. It was concluded that selected trees, even though thorny, could be propagated as thornless clones by using scionwood from branches that had definitely ceased thorn production. Chase noted that 'Millwood' and 'Calhoun' propagated in that manner had remained thornless for 11 years and initiation of thorn production later was considered unlikely. This has been verified in followup observations.

Based on these results, the thorniness of native honeylocust should not be a factor in selection and propagation of the species for future purposes.

Effects on Pasture Grasses

Honeylocust has a finely divided, feathery foliage that allows relatively good light transmission to understory vegetation. For efficient use of the species on farms, it has often been suggested that the trees be spaced throughout pastures or hay fields to provide multiple-cropping benefits.

To evaluate the effects of honeylocust on pastures, a test extending over a 17-year period was conducted in southwestern Virginia (Zarger and Lutz 1961). Treatments on the pasture included (1) honeylocust and phosphate-potash fertilization, (2) honeylocust trees only, (3) phosphate-potash fertilization only, and (4) an untreated check. 'Millwood' honeylocust was planted at 20- x 20-foot spacing, 108 trees per acre, and when 10 years old was thinned to about 28- x 28-foot spacing, 54 trees per acre. Throughout the test the trees had an adverse effect on both the quantity and quality of forage. Fertilization increased forage yields and accelerated tree growth. Forage yields on fertilized pasture with trees were nearly equivalent to yields from unfertilized pasture without trees. Zarger and Lutz noted that the study did not support previous observations of good grass development under honeylocust and they suggested two reasons. First, the density of trees was too high, even at 54 trees per acre, and second, the grazing of livestock was not adequately controlled on the test plots. Since the plots were removed for construction following the test, there was no opportunity for additional thinning to test lower tree densities. It appeared from the study that densities of 35-45 trees per acre might be required to obtain good yields of hay in addition to pod production.

Moore (1948) recommended a density of 35 trees per acre from observations of plantings at Auburn, Alabama. He noted that 2.5 tons per acre of *Lespedeza sericea* hay was harvested every year with trees at that density. Spacing trials warrant inclusion in future field tests or demonstration plantings to develop optimum multicrop benefits.

Feed Value

To determine the feeding value of honeylocust pods, tests were conducted cooperatively by TVA and The University of Tennessee in 1939. In a test with calves, honeylocust pod meal was compared with corn meal in feeding rations for 77 days. The weight gain of animals fed honeylocust was 82 percent of that from corn. A second test was run using white rats, and the results showed honeylocust meal 85 percent as efficient as corn meal. The second test was statistically significant, while the first was not. Common pods were used in both tests. It is likely that pods from selected trees would have shown a higher feeding value.

In two years of tests using selected honeylocust pods in rations for dairy cattle at Auburn, it was found that the pods could be substituted for oats on a pound-for-pound basis (Atkins 1942).

The feed value from honeylocust utilized for ethanol production would be derived from the distillery mash residue. The addition of nutrients from the yeast and fermentation process would likely increase the feed value to livestock. Tests to determine the value of honeylocust stillage should be incorporated in farm trials.

Tree Growth

The growth rate of honeylocust in the Tennessee Valley has been observed to average about 1.5 feet per year in height and 0.3 to 0.5 inch in diameter. On poor sites a height growth of 1 foot per year might be expected and on a good site 2 feet or more during the first 15 years. On a pasture test in Virginia, Zarger and Lutz (1961) found 'Millwood' trees after 10 years to average 20 feet in height and 3 inches in diameter. At 15 years the diameters had increased to about 6 inches. In Alabama, Atkins (1942) reported 5-year-old 'Millwood' and 'Calhoun' trees to average 12.3 feet in height and 3.5 inches in diameter. The growth rates of the two clones at this age were very similar. Observations of open-grown trees on pasture land in the Tennessee Valley indicate that heights usually top out between 40 and 50 feet.

Growth data recorded from hillculture plantations in Iowa, Ohio, and Maryland indicate that slower growth rates of honeylocust can be expected in areas north of the Tennessee Valley (Detwiler 1947).

The moderate growth rates generally observed in honeylocust plantations will not produce a high volume of wood. However, this is of minor importance since the chief value is obtained from the pods. The growth rate is adequate to produce sturdy tree stems and broad open-grown canopies necessary to support heavy crops of fruit pods. Future selections and breeding of honeylocust for yields should also ensure retention of adequate growth capability.

Pod Yields and Fruiting Characteristics

Crop yields of honeylocust pods are most important in assessing the farm potential of the trees for energy production. Observations of single trees or small clumps of honeylocust bearing large quantities of pods have been reported over the years (Detwiler 1947). However, reliable crop data from plantations of clonal selections are scarce.

The data used most often in assessing the performance of 'Millwood' and 'Calhoun' came from the cooperative studies of TVA and Auburn University. From 1938 to 1940, 48 grafted trees of 'Calhoun' and 47 of 'Millwood' were planted. Five years after the initial planting, Atkins (1942) reported these yields:

Variety	Trees in test (number)	Age of trees (years)	Average yield per tree (pounds dry weight)
'Calhoun'	31	3	1.01
'Calhoun'	13	4	5.20
'Calhoun'	4	5	26.38
'Millwood'	31	3	1.27
'Millwood'	11	4	4.98
'Millwood'	5	5	58.30

Yields for the oldest trees above were recorded for an additional five years (Moore 1948) and provide a revealing sequence for 5- to 10-year-old trees as shown below in average dry pounds per tree:

Age	1942 (5)	1943 (6)	1944 (7)	1945 (8)	1946 (9)	1947 (10)	Average
'Calhoun'	26.4	0	32.4	63.8	22.0	46.0	31.8
'Millwood'	58.3	0	146.0	39.5	180.0	12.0	72.6

Although based on a very limited number of trees, the trend toward biennial production is seen in both clones, with the good crop year of one offsetting the bad year of the other. Over the six-year period, the yields of 'Millwood' more than doubled those of 'Calhoun.' In 1943 both clones suffered crop failure attributed to cold weather during flowering and fruit-set.

If it is assumed that these yields could be attained on an acre containing 40 trees, the annual crop fluctuations could cause great problems. An acre of 'Millwood' in 1946 would have produced 7,200 pounds of pods, while in the following year only 480 pounds would have been available. A similar acre planted with 20 'Millwood' and 20 'Calhoun' would have produced 4,040 pounds in 1946 and 1,160 pounds in 1947, thus improving the balance but still presenting a fourfold difference in pods for processing.

The biennial trend in fruit production is common in honeylocust and other tree species. The effect may be lessened by including additional clones in plantations. Breeding to include late flowering and cold hardiness might reduce the possibility of crop failures.

The greatest need in determining yield potential is the establishment of plantations to test clone-site interaction, spacing, and cultural effects on pod yields.

Chemical Analyses

Analyses of honeylocust pods have been conducted over the years by a number of laboratories. Most of the pods analyzed for TVA projects were handled at University of Tennessee facilities.

An analysis of pods from the original 'Millwood' tree in 1938 showed the following constituent percentages on a moisture-free basis:

Constituents	Whole pods	Pods without seeds	Seeds only
Ash	3.75	3.82	10.23
Crude fat (ether extract)	0.81	0.52	3.06
Crude protein (% N x 6.25)	10.15	8.21	28.74
Crude fiber	14.19	13.81	11.02
Nitrogen-free extract	71.10	73.64	46.95
Reducing sugars (glucose)	2.86	3.32	
Nonreducing sugars (sucrose)	29.12	32.22	
Total sugars	31.98	35.54	

Analyses of samples from whole pods from 60 different wild trees tested for TVA gave the following percentage ranges for different constituents (moisture-free basis):

Ash	3.01- 4.87
Crude fat (ether extract)	0.84- 1.80
Crude protein (% N x 6.25)	6.99-15.35
Crude fiber	11.81-24.17
Nitrogen-free extract	58.28-74.81

Although analyses of sugar content were not included for the 60 samples, tests run at different laboratories on many samples of honeylocust pods indicate that wide ranges, 12.9 to 42.3 percent total sugars, exist in wild populations.

Differences in sugar content are likely to be found for trees of the same clone grown in different locations. 'Millwood' pods from trees grown in Beltsville, Maryland, contained 21.07 percent total sugars, while 'Millwood' at Auburn, Alabama, contained 36.8 percent (Detwiler 1948). Also, small differences in sugars were found in pods from the same clonal trees collected in different years.

The ranges of variation in chemical constituents of honeylocust pods are likely to be even greater than those indicated above. Possibly analyses of pods collected in the rangewide Michigan State provenance study will point out pod constituents of particular value. It may be necessary to make more thorough searches to uncover trees with pod constituents best suited for energy production. Breeding may be required to combine desirable chemical traits.

Disease, Insect, and Other Cultural Problems

Observations made during studies of honeylocust in the Tennessee Valley indicated wild trees to be relatively free from insects and diseases. In arboretum and nursery plantings several defoliating, gall, and twig girdling insects occasionally became serious pests. A dieback of branches in young and old trees was sometimes observed and was attributed to an unidentified disease. These problems were not considered major threats to production.

Recent reports from the Middle Atlantic States indicate serious problems with mimosa webworm attacking honeylocust (Tozer 1980). If this insect becomes more widespread, it could cause major problems in plantations. Methods of management or control of the webworm will be needed.

Cattle present a problem in browsing on young honeylocusts. Farm management would require keeping livestock out of young plantations and carefully controlling them in later foraging under the trees. A minor reduction in pod yields might also occur from birds and other wildlife that occasionally feed on the pods.

Discussion of Current Needs

The number of sweet pod selections is far too limited. A thorough, systematic search of wild populations is required to broaden the genetic base and provide material for breeding.

Economical, labor-saving methods of large-scale vegetative propagation are required to multiply selections for general use. Development of efficient methods to grow selections on their own roots would be preferred. Use of tissue culture should be considered.

An essential need exists for establishing well-designed outplantings of honeylocust selections over a wide geographic area and including a range of site conditions. Such plantings can be used to test spacing, cultural techniques and management methods. The current lack of outplanted trees makes it almost impossible to obtain information necessary to properly evaluate the species.

Development of efficient techniques of harvesting the pods should be initiated. Equipment will require testing and refinement based on use in plantations described above. Storage and transport of fruit pods to processing units also will require some developmental work.

Processing methods for using honeylocust pods as feedstock in alcohol production will require testing. The value of stillage residues as livestock feed should also be investigated.

Based on the information and observations provided by early researchers and advocates, serious consideration should be given to a broader application of honeylocust. However, it is clear that reliable, detailed information on many aspects of the species is sparse or lacking. A comprehensive research and development effort is required to fully evaluate the potential of honeylocust as an energy source.

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Appendix I

Honeylocust Selections Remaining in TVA Collection

Clone Name	Location of Original Tree	Traits
'Bessemer'	Unknown	very thorny
'Calhoun'	Etowah Co., Alabama	very high sugar content pods
'Cluster'	Villa Rica, Georgia	very large number of pods per cluster
'Diden'	Scott Co., Tennessee	excellent flavor of pods
'Gadsden'	Etowah Co., Alabama	staminate tree near 'Calhoun'
'Goldworth'	Villa Rica, Georgia	pods very thick, 3/8 inch
'Hartselle	Hartselle, Alabama	staminate, nearly thornless
'Lowland'	Jefferson Co., Tennessee	staminate, very aesthetic
'Markett'	Sandy Springs, South Carolina	moderately thorny
'Millwood'	Haywood Co., North Carolina	high yields, vigorous
'Morrow'	Haywood Co., North Carolina	staminate tree
'Orr'	Hartselle, Alabama	vigorous, nearly thornless
'Penn'	Morgan Co., Alabama	vigorous, nearly thornless
'Smith'	Unknown	staminate tree, vigorous
'Torbett'	Rhea Co., Tennessee	high sugar content pods, vigorous
'Ward'	Haywood Co., North Carolina	staminate tree, nearly thornless

ACORNS FROM NATURAL OAK WOODLANDS AND THEIR UTILIZATION

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ABSTRACT

Oaks are ecologically important and widespread hardwood trees throughout the temperate zones of North America and Eurasia. Their fruits (acorns) have long been considered a valuable wildlife food. However, utilization of acorns by humans and their domestic animals, though dating from preagricultural times, is limited at present. Acorn production varies widely between different species, individuals, geographical locations, and years indicating the interaction of genetic and environmental variables in producing an annual crop. The nutritive value of acorns relative to other forest tree seeds and fruits is low, particularly for protein. However, their high fat content provides an excellent energy source. Palatability and toxicity vary greatly and can pose limitations to their consumption. For example, acorn poisoning in cattle is frequently fatal. Some silvicultural methods for improving acorn production, nutrition, and palatability are presented and discussed.

INTRODUCTION

Oaks (Quercus) are the most important and widespread hardwood trees in North America and Eurasia. The genus is represented by about 58 tree and 10 shrub species distributed across the United States, but reaches its major dominance in the Eastern Deciduous Biome (Fowells 1965). Three important eastern forest types have oaks as a primary

1 The authors acknowledge the editorial assistance of Dr. Thomas M. Hinckley, Associate Professor, College of Forest Resources, University of Washington, Seattle, Washington 98195.

species component: oak-hickory forests, oak-pine forests, and oak-gum-cyprus forests. Oak-hickory forests, stretching from southern New England to Texas, represent the most widespread forest ecosystem in North America. The oak-pine forest is mainly in the south, while oak-gum-cyprus forests are restricted to the Mississippi Delta and other highly productive southern river bottoms. These three forest types represent approximately 35 percent of the commercial forest lands in the United States and over 70 percent of the commercial acreages in the east (USDA Forest Service 1977).

Oaks provide almost every type of product that has ever been derived from trees -- timber, food for humans and animals, fuel, watershed protection, shade and beauty, tannins, various other extractives, and cork (Schopmeyer 1974). Species native to the United States are primarily harvested for lumber, railroad ties, mine timbers, fence-posts, veneer, plywood, and fuelwood. Oak lumber is remanufactured into flooring, cooperage, furniture, general millwork, doors, boxes, pallets, crates, railroad cars, boats and ship parts, caskets, and various agricultural implements. Because of its wide distribution, *Quercus* is of major economic importance throughout the eastern half of the United States.

Oaks also have significant ecological value due to their wide distribution. Because they span a range of altitudes, latitudes, and longitudes, oaks are very important to watershed and airshed qualities, recreational opportunities, and wildlife habitats. Oak buds, twigs, bark, foliage, catkins, and acorns are eaten by a variety of wildlife species, and the tree itself is used by many birds and mammals. Hence, this genus has a very high wildlife value (Gutiérrez et al. 1979), especially for breeding, migrating, and wintering birds (Evans 1978), and for deer (*Odocoileus* spp.) and squirrels (*Sciurus* spp.) (Goodrum et al. 1971).

Acorns have long been considered an important food for humans, their domestic animals, and wildlife in many parts of the world (Smith 1953). However, this important genus generally has been omitted from consideration when discussing the commercial suitability of producing tree nut crops. For example, a recent comprehensive text on tree nut production, processing, and products (Woodroof 1979) does not consider acorns.

The purpose of this paper is to review the production of acorns from natural woodlands in North America, specifically the eastern United States, and to discuss their possible utilization as an annual food and/or energy crop.

CHARACTERISTICS OF THE GENUS *QUERCUS*

Oaks native to the United States are subdivided into two subgenera. Black oaks (subgenus *Erthrobalanus*) have leaves with apex and lobes bristle-tipped, acorns maturing the second year, bark usually blackish and furrowed, and heartwood porous with vessels open. White oaks (subgenus *Lepidobalanus*) have leaves with apex and lobes not bristle-tipped, acorns maturing in one year, bark usually light gray and scaly, and heartwood less porous with vessels closed by tyloses.

Oaks are deciduous in the North Temperate Zone, but are frequently evergreen or have brief leafless periods in the South Temperate Zone. Most oaks are sclerophylls, and have hard leathery leaves of various shapes (e.g., lobed, toothed, or entire) with thick-walled structures and prominent veins. In very dry areas, oaks tend to be quite sclerophyllous and often have narrow or deeply-cut leaves with small leaf surfaces in order to prevent excessive desiccation. Mesophytic oaks, however, may have thin succulent leaves, particularly under shade conditions (Spurr and Barnes 1980).

Except for a few species like Quercus ilicifolia, Q. laurifolia, and Q. nuttallii, most oaks must be at least 20 years old before they produce an acorn crop. Seed sizes vary greatly between species as do the intervals between successive acorn crops; intraspecific variability also seems to be high. Complete life histories, associated trees and shrubs, and a discussion of races and hybrids for various oak species may be found in Fowells (1974), while acorn characteristics may be found in Schopmeyer (1974).

Quercus is the most abundant and widely distributed tree genus in the eastern half of the United States. This genus shows a great deal of genetic intra- and interspecific variability which results in a wide tolerance of ecological conditions. In general, representatives can be found from the deep south where average annual temperatures and precipitations are high, frosts rare, and growing seasons long (e.g., Q. laurifolia, Q. shumardii, and Q. virginiana), to the Canadian-American border where environmental extremes are great and growing seasons short (e.g., Q. rubra, Q. palustris, and Q. macrocarpa.) Some species are widely distributed (e.g., Q. alba, Q. rubra, and Q. velutina), while others are restricted to the south (e.g., Q. laurifolia, Q. nuttallii, and Q. virginiana), or Lake States (e.g., Q. bicolor).

Oaks are primarily xerophytes but some species are well adapted to mesic and hydric conditions (Spurr and Barnes 1980). For example, Q. falacata var. pagodaefolia is the most important bottomland oak in the Mississippi Valley flood-plain, while Q. rubra does best on mesic sites. Q. alba and Q. velutina have wide ecological ranges but are most characteristically found on drier sites. Q. prinus is dominant on very dry hillsides and mountain slopes; while an entire series of shrub oaks (e.g. Q. ilicifolia, Q. laevis, and Q. marilandica) grow on very dry, infertile sand plains.

ACORN PRODUCTION

FLOWERING, FRUITING, AND GERMINATION

Oaks are monoecious and produce small flowers in early spring (February through May) slightly before or along with the leaves. Flowering is normally completed before the leaves are fully expanded. The staminate flowers are borne in slender, yellowish, catkins; pistillate flowers are usually solitary and greenish. Staminate

flowers develop from leaf axils of the previous year, while pistillate flowers develop from axils of leaves of the current year.

The oak fruit, an acorn or nut, matures in one year (white oaks) or in two years (black oaks). The acorns are normally one-seeded, partially enclosed by a scaly cup, and occur singly or in clusters of two to five. They are 0.25 to 1.50 inches long, subglobose to oblong, hard-shelled, short-pointed at the apex, and marked with a circular scar at their bases which are covered by the cups. Fruit ripening and seed dispersal occur in the autumn (late August to early December). The embryo has two fleshy cotylendons and no endosperm. Acorns are generally green when unripe, but turn brown and sometimes black upon ripening.

Almost all acorns of the white oak group have little or no dormancy, and typically germinate soon after falling from the tree. However, at northern latitudes dormancy will occur to prevent freezing injury during the winter. Acorns of the black oak group exhibit complete embryo dormancy and do not germinate until the following spring. Hence, stratification (normally 30 to 120 days in a moist medium at 32^{o} to 41^{o}F; Schopmeyer 1974) is required before germination tests or planting.

CONTROL AND REGULATION

The production of an acorn crop involves a specific series of phenological steps (male and female flower initiation and development; pollen dispersion, pollination, and fertilization; ovule development and maturation), and numerous interrelated physiological processes. Genetic differences within and between oak species greatly affect the maximum size of individual acorns and seeds, and the potential crop yield (discussed later). However, acorn production is also closely related to various environmental factors, and the amount of stored carbohydrate reserves.

The internal requirements for reproductive growth are similar to those needed for vegetative growth -- carbohydrates, water, hormones (e.g., auxins, gibberellins, and ethylene), and nutrients (e.g., nitrogen, potassium, and phosphorus). Hence, reproductive and vegetative growth are often negatively correlated because rapidly growing reproductive tissues are strong sinks for carbohydrates and nutrients. The inhibitory effect of heavy fruiting on vegetative growth often occurs both during the current year and during the subsequent year(s).

A variety of environmental factors interact to influence reproductive growth both directly, as by thermal injury, and indirectly, by altering physiological processes (especially carbohydrate and hormone relations) (Kramer and Kozlowski 1979). Because of the interrelationships between vegetative and reproductive growth, any external factor that influences shoot, cambial, or root growth may eventually modify reproductive growth and development. Among the most important are light, temperature, water, and mineral supply.

Reduced light intensity lowers fruit crop yield by inhibiting floral initiation, fruit set, and fruit development. This will affect both the number of acorns produced and the seed sizes.

Temperature influences many aspects of reproductive growth, including floral initiation, release from bud dormancy, anthesis, fruit set, and growth of fruits (Kramer and Kozlowski 1979). Bud break from dormancy normally requires a short period of low temperatures, but all other processes (induction of flowering through acorn maturation) need reasonably high temperatures. In addition, flowers and fruits are commonly injured by extremely low or high temperatures.

Direct freezing injury to reproductive tissues is very common (Kramer and Kozlowski 1979). Such injury includes midwinter killing of dormant flower buds, a major factor in determining the northern extent of oak species (along with freezing injury to other meristems and vegetative parts). In addition, spring and fall damage to flowers and fruits due to freezing temperatures also occur. This is a major cause of early floral abortions and acorn mortalities.

Wolgast and Trout (1979) have examined the effect of a late spring freeze (three consecutive days in late May) on acorn production in Q. ilicifolia. They observed a significant loss of the year's acorn crop due to freezing damage to stems and branches holding immature acorns. Normally, low temperatures are not thought to affect immature acorn development. However, pistillate flowers are very susceptible to frost damage. Since Q. ilicifolia is in the black oak group requiring two years to mature acorns, the loss of pistillate flowers will greatly reduce the following year's crop (Goodrum et al. 1971, Wolgast and Trout 1979). In contrast, early spring freezes limit current acorn yields in the white oak group (Sharp and Chisman 1961, Sharp and Sprague 1967, Goodrum et al. 1971).

Mineral requirements are very high for reproductive tissue. Low soil nutrient levels can inhibit floral initiation, fruit set, and growth rate, and ultimately fruit size (Kramer and Kozlowski 1979). Hence, fertilization should be expected to improve acorn production (discussed later).

Water is also important to acorn production. Severe water deficits can limit each phase of the reproductive cycle by directly reducing cell division and elongation. Furthermore, water-limiting conditions promote stomatal closure which reduces photosynthesis and the accumulation of carbohydrates required for all growth processes. These relationships are further complicated by the timing of water deficit conditions in relation to acorn production and maturation processes. Hence, effects vary with the amount and distribution (i.e., timing) of rainfall, the degree of plant water stress at critical reproductive phases, the soil type, and tree species (Kramer and Kozlowski 1979).

Warm, desiccating winds during male flowering and pollen dispersal have been shown to reduce acorn yields in various white oaks (Sharp and Sprague 1967). However, no correlation was noted between acorn production and precipitation, relative humidity, or vapor pressure deficit by Sharp and Sprague (1967). Goodrum et al. (1971) also report the lack of a close relationship between rainfall and acorn production from six oak species in Louisiana and eastern Texas.

ACORN PRODUCTION RATES

Many forest trees (e.g., *Larix* spp., *Pinus* spp., *Betula papyrifera*, and *Liriodendron tulipifera*) have seed outputs exceeding 10,000 per year (Harper and White 1974). In contrast, *Quercus* species have very low seed outputs, seldom reaching 2000 acorns even in the best years. However, the seeds of *Quercus* are consistently heavier than most other seeds, and thus contain a greater amount of stored energy (Schopmeyer 1974). In general, white oak acorns are larger, heavier, and have a higher moisture content than black oak acorns (Goodrum et al. 1971).

In *Quercus*, as in many other forest trees, high seed outputs depend on the trees having well developed crowns which are fully exposed to sunlight (Downs 1949, Harper and White 1974). Goodrum et al. (1971) in their comprehensive examination of various white and black oak species have discussed this relationship. Acorn yield per tree increased with increasing crown size (Table 1). Most of the relationships were curvilinear indicating a gradual loss in production from the largest trees. In support, they observed decreasing yields at tree ages over about 100 years. In addition, they reported a linear relationship between acorn production and bole diameter, with a greater percentage of larger trees generally producing acorns. Thus, the output from a dense stand comes primarily from those few individuals whose crowns are well exposed in the canopy (Gysel 1971) (discussed later). Goodrum and his colleagues (1971) noted that radial growth was a poor predictor of acorn yield, indicating the interrelation between vegetative and reproductive growth. However, oaks having a radial growth rate in excess of 0.6 inches during the past 10 years generally had the highest acorn yields.

In general, oaks produce good acorn crops every three or four years (Fowells 1965, Schopmeyer 1974). This is due to the interaction between various environmental factors (especially the frequency of spring frosts), plus the need to build up internal carbohydrate levels necessary to produce a relatively large amount of reproductive biomass (Downs 1949).

The production of acorns is quite variable between species as well as from year-to-year. Results from Goodrum et al. (1971) have indicated that there is generally no regular cycle of good or poor years making predictions for a species and different years difficult (Table 2). During their 18-year study, relatively good yields occurred in 1951, 1953, 1954, 1959, 1960, and 1961; low yields occurred in 1957, 1958, 1962, 1964, and 1966. An early spring freeze in 1955 nearly eliminated the acorn yield from white oaks but had a limited effect on the yield from black oaks. The 1956 yield from black oaks, however, was very low due to the destruction of pistillate flowers during the 1955 freeze.

Genetic variability was noted in the results of Goodrum et al. (1971) as certain trees of the same species and diameter class regularly produced more, or fewer, acorns than the average. In addition, failure by an individual tree to produce any acorns occurred more frequently with the relatively poor producers. However, there was a tendency for a

Table 1. Expected yield of acorns (pounds fresh weight) by Quercus species and 2-foot crown radius classes (6-foot class = 5.0 to 6.9 feet) (adapted from Goodrum et al. 1971).

CROWN CLASS	WHITE OAKS Q. alba	WHITE OAKS Q. stellata	BLACK OAKS Q. falcata	BLACK OAKS Q. nigra
6	----	0.3	----	----
10	----	2.0	0.5	0.1
14	5.7	5.1	3.0	2.2
18	18.1	9.4	7.3	10.2
22	37.1	15.1	13.4	24.0
24	49.1	18.2	17.1	33.0
26	----	----	21.3	----
28	----	----	26.0	----
30	----	----	31.0	----

Table 2. Average weight (pounds fresh weight) of acorns produced per year, and average percentage of trees producing acorns per year (adapted from Goodrum et al. 1971).

	Averages for					
	3 White Oaks spp.		4 Black Oaks spp.		All species	
Year	Pounds	Percent	Pounds	Percent	Pounds	Percent
1950	2.0	48	2.1	80	2.1	69
1951	8.0	65	2.6	61	4.9	63
1952	1.3	52	3.6	68	2.6	61
1953	6.2	54	6.0	81	6.1	69
1954	6.2	71	4.3	75	5.1	73
1955	0.1	8	3.4	84	2.0	51
1956	2.9	66	0.1	29	1.0	41
1957	2.2	72	0.1	33	0.8	46
1958	0.5	15	2.0	59	0.8	44
1959	4.1	83	6.6	89	5.8	87

higher percentage of trees to bear acorns in good yielding years than in poor (Table 2). Therefore, the increased yield during good years came from individual trees yielding more acorns, and more trees producing a crop.

Variations in acorn production from individual trees are reflected in total yields from a woodland. Acorn production between 1956 and 1969 from a hardwood stand (Q. phellos, Q. lyrata, and Q. falcata var. pagodaefolia) in southeastern Missouri has been shown to vary from 180,000 acorns per acre in 1957 to 3,300 acorns per acre in 1967; average production was 62,700 acorns per acre per year (McQuilkin and Musbach 1977). The yield increased with stand density and tree size. Shaw (1968) in a 120-year-old oak woodland in Britain has reported yields of 167,000, 39,700 and 0 acorns per acre in three consecutive years.

Beck (1977) studied acorn production from a southern Appalachian oak forest in western North Carolina; modest yields occurred in nine years, four years were exceptional, and three years had very low yields (Table 3). Total production from the stand over the 12 year study period varied from 2.6 pounds per acre in 1973 to 1,012.7 pounds per acre in 1967; the average yield was 289 pounds per acre per year. Contributions from the various species varied between different years as previously discussed. However, there were no complete crop failures even during the poorest year (1973 due to a mid-May freeze), because of the complementary effect of having a number of different oak species present. Similar results have been noted by Goodrum et al. (1971) (Table 2). In both studies, extremely poor years seldom seemed to occur consecutively.

The net production of viable acorns from a tree or woodland can be very different from the number of acorns reaching maturity. The percent of sound seeds is normally reduced by predation from insect larvae, squirrels, birds, and other wildlife that utilize acorns as food (discussed later). Downs (1949) has reported a 30 percent loss of acorns due to insect larvae and a 24 percent loss due to squirrels and birds; losses were greater in average production years than in poor years. Cypert and Webster (1948) have reported a 13 percent loss to blue jays (Cyanocitta cristata) and red-headed woodpeckers (Melanerpes erythrocephalus) before acorns reached the ground. Christison and Korschgen (1955) reported a 13 percent loss to squirrels and birds. In addition, one deer can eat an entire year's acorn crop from 30 acres of woodland (Downs 1949). As a net result, Downs indicated that eight to ten trees (17 inches in diameter at breast height) per acre produced only 1,500 to 2,000 sound acorns in a good crop year after insect and animal losses occurred.

McQuilkin and Musbach (1977) reported a 25 percent insect infestation in acorns from Q. phellos, Q. lyrata, and Q. falcata var. pagodaefolia between 1956 and 1969 in southeast Missouri. The percentage of insect infested acorns decreased with increasing crop size.

Table 3. Total acorn production (pounds fresh weight per acre) and percentage of sound seed per year for various *Quercus* species (from Beck 1977).

Year	Q. rubra		Q. velutina		Q. coccinea		Q. alba		Q. prinus		Total	
	Total	Sound	Total	Sound	Total	Sound	Total	Sound	Total	Sound	Total	Sound
1962	51.6	64	27.2	33	42.2	31	84.8	14	10.5	33	216.3	36
1963	29.1	32	11.1	8	42.5	17	387.5	48	100.0	81	570.2	51
1964	--	--	8.0	28	15.0	21	5.1	44	1.4	0	29.5	25
1965	7.3	17	1.4	21	.5	50	131.0	18	.7	0	140.9	19
1966	255.2	84	52.7	75	227.1	68	9.2	61	.7	0	544.9	77
1967	23.2	40	26.9	46	42.6	38	683.8	78	236.2	94	1,012.7	79
1968	--	--	1.8	61	--	--	4.8	89	--	--	6.6	80
1969	5.9	21	--	--	--	--	113.4	54	1.6	0	120.9	51
1970	69.5	57	18.2	33	43.3	26	6.0	54	.7	0	137.7	46
1971	166.5	73	27.4	61	90.3	58	305.5	75	23.6	53	613.3	70
1972	16.5	64	17.3	59	32.1	63	8.4	84	1.4	50	75.7	64
1973	--	--	--	--	--	--	2.6	29	--	--	2.6	29
Total	624.8	70	192.0	51	535.6	52	1,742.1	61	376.8	85	3,471.3	--
Average	52		16		45		145		31		289	65

Beck (1977) has observed a wide variability in seed soundness (i.e., nonweevil infested) of mature acorns between different species and different years (Table 3). Weevils infested about 35 percent of the acorns in good crop years and about 65 percent in poor years. Though infested, these acorns should still be partially available for wildlife food. Beck's results, as well as those of Goodrum et al. (1971), indicated greater infestations in black oaks compared to white oaks (Table 3). This is surprising given the higher tannin levels characteristic of the black oak group (discussed later), but may be partially related to differences in acorn maturation rates.

ACORN UTILIZATION

CHEMICAL COMPOSITION

As a group, seeds differ from other plant parts in having a high concentration of energy-rich lipids, in addition to large amounts of carbohydrates and proteins. Although some seed proteins, such as enzyme proteins and nucleoproteins, are metabolically active, a large proportion is inactive (Kramer and Kozlowski 1979). In addition to proteins, the nitrogenous material in seeds includes free amino acids and amides (glutamine and asparagine). Other seed constituents include variable quantities of minerals, phosphorus-containing compounds (e.g., phosphates, nucleotides, phospholipids, nucleoproteins), nucleic acids, alkaloids, organic acids, phytosterols, pigments, phenolic compounds, vitamins, and hormonal growth regulators.

Short and Epps (1976) have investigated the chemical composition and digestibility of acorns from 11 Quercus species relative to other seeds and fruits in an east Texas hardwood forest. Compared to the other forest seeds and fruits, acorns were: (1) low in protein and fiber, (2) high in digestible cell contents (e.g., lipids, starches, soluble protein, sugar, and pectins), and (3) low in calcium (Table 4). The protein contents were below those required for an adequate animal diet. Hence, the major utility of acorns as a food crop comes primarily from their high carbohydrate and fat contents (Downs 1949), and their high palatability and digestibility (Short and Epps 1976). This makes them an excellent energy source for many animals (Ofcarcik and Burns 1971).

There is often wide variation in the seed composition of different species within the same genus, and this is the case with Quercus (Ofcarcik and Burns 1971). Although the chemical composition of acorns is genetically determined, the relative amounts of various constituents can also be affected by specific site factors (Kramer and Kozlowski 1979). Thus, Ofcarcik and Burns (1971) have reported varietal differences in acorn constituents which often exceeded interspecific variations (Table 5).

In Quercus, acorn constituents separate nicely between the white and black oak groups (Ofcarcik and Burns 1971, Short 1976, Short and Epps 1976). In general, the white oak group has higher nitrogen-free extract, (i.e., the substance remaining after crude fat, protein, ash, and crude fiber are subtracted from total dry matter), ash, and hemi-

Table 4. Averages for chemical constituents (percent oven-dry weight) and estimated true dry matter digestibilities of various groups of seeds and fruits from a southern hardwood forest (adapted from Short and Epps 1976).

Constituent	Fleshy Fruits (47)[1]	Legumes (9)	Dried Fruits (11)	Kernels (5)	Acorns White (5)	Acorns Black (6)
protein	8.4	31.2	11.9	13.8	5.9	5.9
fat	11.0	6.7	7.8	45.8	4.3	17.9
fiber	24.1	15.6	40.6	3.4	18.7	18.4
CWC[2]	40.9	40.4	58.9	17.8	47.0	34.8
hemicellulose	11.0	20.0	10.0	7.1	23.2	10.2
NFE[3]	----	----	----	----	69.2	52.6
ash	----	----	----	----	2.7	2.2
ETDMD[4]	64.4	78.0	50.8	81.4	59.8	68.5
tannin[5]	----	----	----	----	1.0	7.1
Ca	0.56	0.24	0.38	0.13	0.15	0.24
P	0.22	0.54	0.24	0.34	0.09	0.10

1 number of species sampled
2 CWC = cell wall components
3 NFE = nitrogen-free extract
4 ETDMD = estimated dry-matter digestibility
5 from Ofcarcik and Burns 1971

Table 5. Varietal averages and ranges for protein and tannin constituents (percent oven-dry weight) of acorn seeds from various *Quercus* species (adapted from Ofcarcik and Burns 1971).

Species	Protein Average	Protein Range	Tannins Average	Tannins Range
White Oaks:				
Q. macrocarpa	3.9	3.0-5.1	0.7	0.1-2.7
Q. virginiana	7.4	6.2-8.6	0.9	0.2-2.5
Q. stellata	6.2	4.5-7.6	0.9	0.2-1.9
Black Oaks:				
Q. falcata	6.9	6.8-7.0	8.7	8.6-8.8
Q. nigra	5.4	4.9-5.7	8.8	7.5-10.0
Q. phellos	5.2	4.9-6.0	7.2	6.8-8.0

cellulose levels; and lower crude fat, dry weight, and tannin levels than the black oak group (Table 4). The higher crude fat levels typical of black oaks mean more digestible energy. However, white oaks, having lower tannin levels (Table 5), are generally more palatable than black oaks (Short and Epps 1976).

UTILIZATION BY ANIMALS

Acorns, being rich in carbohydrates, fats and vitamins, are an important food crop for some wildlife and domestic animals (Downs 1949). Hence, their food value has long been recognized by wildlife biologists concerned with maintaining and improving wildlife habitats (Van Dersal 1938).

Many wildlife species respond to the immediate availability and quantity of acorns and use them as an occasional or seasonal food; others are very dependent on this food source. Acorns are now considered to be an important food for wild turkeys (*Meleagris gallopavo*), quail (*Colinus virginianus*), crows (*Corvus brachyrhynchos*), woodpeckers (*Melanerpes* spp. and *Dendrocopos* spp.), blue jays, grey and fox squirrels (Sciurus *carolinensis* and *S. niger*), grey foxes (*Urocyon cinereoargenteus*), rabbits (*Sylvilagus* spp.), white-tailed deer (*Odocoileus virginianus*), and black bears (*Ursus americanus*) (Goodrum et al. 1971, Wolgast and Stout 1977).

Short (1976) examined the intake and digestion of 11 species of acorns by adult fox squirrels, and observed both intra- and interspecific variations in digestibility. Thus, certain tree species were more important in maintaining fox squirrel energy and nutrient balances. Crude fat levels accounted for 18.1 to 36.9 percent of the apparently digested dry matter in acorns from the black oak group, but for only 4.1 to 9.6 percent from the white oak group. Average nitrogen-free extract was a significantly greater proportion of the apparently digested dry matter in acorns from the white oak group. The amount of crude protein digested was low for all species, ranging from 4.7 percent of the apparently digested dry matter to less than 1 percent, as were nitrogen balances (i.e., an indication of the inadequacy of dietary protein). Apparently, the available nitrogen in acorns is not sufficient to ensure normal maintenance of body nitrogen in adult squirrels. Low levels of nitrogen may result both from small amounts of crude protein in the acorns and from the presence of tannins, which may restrict metabolic use of those proteins present.

Tannins are polyphenolics that can form heterogeneous complexes with plant proteins and with herbivore digestive proteins inhibiting their activity (Short 1976). Hence, acorns with high tannin levels (e.g., the black oak group) generally have a low actual digestibility as well as proteins that are complexed and unavailable. This reduces the value of these acorns as a wildlife food crop. However, from the tree's perspective high tannin levels provide a level of protection from fungus, bacteria, and insect and animal herbivory.

Although acorns from the white oak group may be the more palatable of the two groups due to their lower tannin levels, black oak acorns are also an important source of energy. Without being cached, white oak group acorns germinate earlier and are useful to squirrels for a shorter period of the autumn-winter season than are acorns from the black oak group.

Acorns have been used extensively around the world as a domestic animal feed; especially for hogs in Europe (Smith 1953). Their high nutrient value is especially useful when supplemented with other feeds high in protein (Downs 1949); however, their high tannin contents can cause digestive problems.

As early as 1892, Dun referred to the astringent action of oak bark due to its tannic acid content, and stated that acorns, though high in nutritive value, must be fed sparingly to prevent problems. Other early writers (e.g., Moussu and Dollar 1905) mention the nutritive value of Q. rubor and Q. sessiliflora acorns for swine, but cautioned that "acorns constitute a dangerous food for young cattle, especially when eaten before they are ripe and when herbage or other feeding is scanty or restricted."

Recent studies have examined the toxic effect of acorn consumption on cattle (McGowan 1970, Beck and Beck 1972, Stöber et al. 1976). Acorn poisoning symptoms included dullness, anorexia, constipation, followed by diarrhea, straining, colic, head carried low, eyes retracted, mucus discharge from eyes and nose, and distended abdomen; death normally resulted soon after hospitalization regardless of treatment. Autopsies on dead or destroyed animals revealed diffuse subcutaneous hemorrhages throughout the body cavities. Interestingly, only a portion of the herds examined seemed to be affected; usually younger animals that had acquired a preference for acorns. Acorn poisoning seemed to be a major problem only when acorn crops were heavy, and then only after a violent storm had caused premature shedding of large quantities of unripe nuts (Beck and Beck 1972, Stöber et al. 1976). As a consequence, acorn poisoning has been misdiagnosed in the field as "lightning death" (Beck and Beck 1972).

Tannin levels typically decrease during the maturation process, thus making ripe acorns less poisonous than unripe acorns or green leaves (Stöber et al. 1976). Hence, prevention of acorn poisoning involves keeping cattle out of woodlands during the acorn-ripening process.

UTILIZATION BY HUMANS

Acorns have been part of the human diet for centuries; in fact their importance in Europe and the Near East predates agricultural civilizations (Bohrer 1972). Oak forests originally covered the hills throughout the Fertile Crescent, and acorns often provided winter fodder for animals and human food during times of famine in this area. Acorns were either roasted and eaten; or ground into flour, leached with water to remove tannins, and baked into thin cakes or mixed with buttermilk and water before being consumed. Written recommendations indicating

the need to soak acorns prior to consumption goes back over 2,000 years.

Bohrer (1972) in his "acorn/cereal theory" outlined the possible importance of acorns in preagricultural times. He postulated that acorns were a staple in the human diet throughout the Fertile Crescent due to the extensive oak forests originally covering this region. However, increased human use of this forest for food, fiber, fuelwood, and animal feed, along with the grazing of large goat herds, led to deforestation and the invasion of wild grasses (e.g., wheats and barleys). As deforestation continued and the grasslands spread, native peoples became more dependent upon cereal grains for food, and the oak forests receded to the high mountains. Continued over-utilization of these oak forests led to their complete destruction and elimination as a major forest type. Such a hypothesis (i.e., human impact creating a new plant community throughout the Fertile Crescent) is supported by the archaeological record which indicates the gradual destruction of oak forests throughout the Near East.

In North America, Indians ground acorn seeds, leached out their bitterness with warm water, dried, and cooked them into mush or bread. White oaks, especially Q. alba and Q. prinus, were preferred over the black oak group due to their less-bitter taste (i.e., lower tannin levels). Early pioneers utilized acorns as well. In fact Q. muehlenbergii, now common in the Lake States and Midwest, was harvested almost to extinction two centuries ago because of its delightful fresh acorns and coffee-substitute qualities of the roasted nuts (Ofcarcik et al. 1971).

The use of acorns for human food has persisted into the twentieth century in Europe and the United States. Early in the century, poor people in Italy and Spain utilized acorns for bread, cake, and as a coffee substitute, thus supplementing up to 25 percent of their diets with acorns (Ofcarcik et al. 1971). Currently in the United States, acorns are used only in a few special breads and as a general meal (Smith 1953). Since the level of tannin affects the degree of bitterness, many acorn species are unpalatable (e.g., most black oaks). Many of the acorns from white oaks, however, are practically bitter-free, sweet, and quite flavorful (Ofcarcik et al. 1971).

Owing to their complex composition, acorns are potential sources for a variety of extracts (Ofcarcik et al. 1971). American Indians, for example, extracted edible fatty-substances by pressing or boiling acorns (Smith 1953). In addition, tannins have been extracted for various purposes (Woodroof 1979).

Because of the high carbohydrate and fat levels in acorns, it is tempting to consider them a possible source of renewable energy. However, the potential usefulness of acorns or their derivatives in the production of useable forms of energy (other than food-energy) is currently unexplored. Carbohydrates can be converted and/or upgraded to more useful fuel products, such as alcohol through fermentation. Brazil is currently mounting a massive effort to produce alcohol from sugarcane,

and similar preliminary considerations are being given to the use of silage corn and crop residues in the United States.

Even though acorns are a carbohydrate source that could be used in fermentation, their yields are insignificant relative to other possible sources. For example, the greatest annual acorn production rate found in the literature was for southern Appalachian oak forests -- 1,012.7 pounds per acre (Beck 1977; Table 3). By assuming a 40 percent average moisture content (Goodrum et al. 1971) and an average carbohydrate level of 50 percent (Kramer and Kozlowski 1979), maximum annual stand production of carbohydrates from acorns may be only about 300 pounds per acre. In contrast, silage corn is capable of producing 12,000 to 14,000 pounds of oven-dry, above ground biomass per acre per year (McRae et al. 1977). Since about 70 percent of this biomass may be in the form of carbohydrates (Junk and Pancoast 1973), carbohydrate yields from silage corn may be between 8,400 and 9,800 pounds per acre per year. These data gain additional significance when one considers that about 1,500 pounds of carbohydrates are required to produce about 100 gallons of alcohol given current fermentaion techniques (P. Felker, this volume).

The production of fuel energy from fats extracted from acorns is another theoretical possibility. While vegetable and animal fats were once used widely for lighting purposes, they have long been replaced by other methods. Fats, however, are still used in some special "cleanoil" products and in the production of candles. Oils used for cooking, cosmetics, pharmaceuticals, and lubricants are pressed, extracted, distilled, or centrifuged from many tree nuts including almonds, beechnuts, and pecans (Woodroof 1979). Most commercial tree nuts, unshelled, vary from 22 to 38 percent in crude fats (Woodroof 1979). Fat levels in acorns vary from 2.9 to 26.2 percent (Short 1976), with white oaks having very low levels compared to black oaks (Table 4). Though acorns seem to be somewhat lower in fat contents than many commercial nuts, extraction for fats is possible. However, the low yield probably would make exploitation uneconomical (Marwat et al. 1978).

It has been known for decades (Mandlekar et al. 1946) that vegetable oils, when subjected to thermal decomposition under pressure, release large quantities of saturated and unsaturated hydrocarbons. In fact, vegetable fats, such as palm oil, have been used to produce diesel and light motor fuels in China during times of petroleum scarcity (Swern 1964). To date, acorns and other tree nuts have not been used for such purposes.

SILVICULTURAL CHARACTERISTICS

GENETIC MANIPULATION

Genetic selection and improvement offer possibilities for improving acorn qualities and production quantities. There seems to be no work available in this area comparable to that done with Pinus and Populus species. Since there is a wide intra- and interspecific variation as to production yields and acorn quality (primarily related to tannin levels), this area offers great potential for future work. Currently,

however, acorn production from natural woodlands can best be improved by realizing that genetic control is occurring, and that production can be enhanced by selecting those species, and those individuals within a species, that historically produce larger quantities of quality acorns.

STAND MANIPULATION

Because of the interaction between tree genetics and various environmental variables, there are certain silvicultural practices that can affect the quality and quantity of acorns produced from a woodland. Many *Quercus* species will grow reasonably well on dry sites with low productivities for traditional agricultural crops. Hence, managing woodlands for acorn production could utilize marginal lands while not conflicting with commercial agriculture. In addition, most oak species are highly valuable for lumber, and harvesting acorn crops need not degrade this use.

Stand composition is very important in ensuring a high quality, abundant acorn crop every year. The development of stands composed of various oak species (i.e., polycultures) will stabilize annual acorn yields from the stand. For example, a mix of species from the black oak and white oak groups will prevent the destruction of the stand's acorn crop due to one poor spring (Beck 1977, Wolgast 1979). Of course, the black oak group is generally higher in tannins, but individual tree selection could be carried out to enhance the number of low-tannin oaks present (Ofcarcik and Burns 1971).

The best method for manipulating stand composition is through the selective removal of undesirable species and individuals (i.e., thinning). Because of their low survival rate under field conditions, large scale planting of most hardwood species is not recommended. Hence, species composition can best be altered by selectively removing those oaks poor in acorn production and/or quality. In addition, vigorous, dominant oaks will produce more seed than intermediate or suppressed individuals; when competition is severe due to crowding, suppressed trees will fail to produce an acorn crop (Kramer and Kozlowski 1979). Proper thinning reduces this competition and generally increases acorn production from a stand.

Thinning increases the amount of light reaching the crowns of the remaining trees as well as provides more water and nutrients. Such conditions have been shown to have a positive effect on acorn production (Harper and White 1974). Young stands, however, may not be greatly affected by stand density. Wolgast and Stout (1977) have shown that stand density had relatively little influence on acorn production from *Q. ilicifolia* stands up to at least 13-years-old.

Since soil nutrient levels are important to the reproductive process, the addition of fertilizers has been shown to have a positive influence on acorn production rates. The greatest effect is generally exerted on a single seed crop; therefore, continuous high production would require repeated fertilizer applications (Kramer and Kozlowski 1979). Stimula-

tion of flower bud formation is best accomplished by fertilizing early in the spring before new buds are differentiated. Hence, with the white oak group, spring fertilization will affect both the production of flowers and the seed crop during the first year (Detwiler 1943). In contrast, with black oaks, spring applications of fertilizer will affect flowering in the spring of the subsequent year and in the number of ripened seeds later that fall. Fertilization seems to have little effect on immature acorns. For example, Wolfast and Stout (1977) found that fertilization did not influence the mature Q. ilicifolia acorn crop during the fall following first application, but there was a positive response the following year. Total acorn weights increased with fertilization.

In general, better responses occur when fertilization is used in combination with thinning and/or irrigation (Kramer and Kozlowski 1979). Stand age also seems to be important. For example, Wolfast and Stout (1977) with Q. ilicifolia found that age and fertilization interacted in their effect on acorn productivity at all three development stages -- pistillate flowers, immature acorns, and mature acorns. The greatest effect occurred with 9-year-old stands compared to 13-year-old stands; no response occurred with 5-year-old trees. Acorn production decreased between 5- and 13-year-old stands when unfertilized.

The addition of supplemental water (irrigation) can also improve acorn production; however, this relationship is very complex (Kramer and Kozlowski 1979). Stimulation of reproductive growth occurs best in dry areas. The resulting impact is closely related to the timing of irrigation due to the differential effect of soil water levels on various reproductive stages. However, cost/benefit analyses of both irrigation and fertilization would likely preclude these activities from a management plan.

MANAGEMENT CONFLICTS

Managing a woodland for acorn production should be compatible with other uses of the land. However, care must be taken in order to prevent possible conflicts. For example, the highest acorn production from a tree will occur when it receives the largest amount of direct sunlight. Hence, extremely heavy thinnings will promote the development of large, full crowns that receive large amounts of light. However, such thinnings will result in stands which do not fully occupy the site. A reduction in the quantity of wood fiber will therefore occur. Furthermore, large crowns promote more branching which reduces the quality of tree stems for lumber.

The greatest potential impact from harvesting acorn crops probably involves the loss of this valuable wildlife food from a woodland. As has been discussed earlier, many wildlife species rely heavily on acorns for an energy source. Reducing the quantity of acorns will result in either a loss or reduction of certain wildlife species, or their shift to other food sources. These alternate food sources may be agricultural crops which will have negative repercussions. Many landowners are very interested in maintaining or improving the wildlife habitat quality of their lands and the loss of this valuable food may

not be desirable (Gutiérrez et al. 1979).

CONCLUSIONS

The current potential for utilizing acorns from natural oak woodlands is limited owing to their usefulness to wildlife, their low and variable annual production rates, and the lack of appropriate management practices. Hence, they probably will continue to be used by humans only in special breads and meals, and as a supplemental feed for domestic animals. However, certain exotic *Quercus* species managed in plantations could be expected to produce much higher annual yields (J. Hanover, personal communication), and may provide cost-effective amounts of carbohydrates and fats for human consumption or liquid energy production. These possibilities have not been investigated to date.

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CHESTNUT AND OTHER NUT TREES IN THE NORTHERN UNITED STATES

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Abstract

Chestnut, filbert, hickory and several species of walnut are notable food bearing plants in the North; however, they are seldom grown in commercial orchards. Climate, yield, topography, technical knowledge, land costs, and labor costs have put nut trees at a disadvantage compared with other crops. We lack simple, convenient measures of success for crops other than the traditional yield per acre and net dollar return per year. The relative value and uses of "by-products", such as wood, shells, and husks, need to be further explored. Managers of small, mixed plantings are potentially faced with the sum of all the problems encountered with each of the species as grown separately in monoculture. Knowledge of cultivar selection, pest control, soil management, harvesting, and marketing is often unknown or unavailable to the grower.

Nut trees sound like the panacea for food and fiber production on hilly marginal farm lands presently producing little except fire wood. Chestnut, filbert, hickory, Persian walnut, black walnut, and butternut can all produce large crops of edible nuts. Except for the West Coast states and central and southern U.S. for pecans, plantings of these trees have had only limited commercial success. Production information on the different species, especially in the northeastern third of the U.S., is reviewed, followed by data on kernel, shell, and husk nutrients and a discussion of the problems of growing and determining the value of nut trees in yards and small farms.

First we should know the value of nuts produced in domestic commercial orchards. Ranked in decreasing order of production on a kernel weight basis are almonds, Persian walnuts, pecans, filberts, and macadamias. Total production ranges between 500 and 600 million pounds of kernels a year. Almonds account for 60% or more, Persian walnuts 19%, pecans 16%, filberts 1.8%, macadamias 1.3%, and pistachios less than 1% (Axer, 1980). About half of the pecan production is from managed natural tree stands, in contrast, the others are all in plantations of named cultivars.

Chestnuts

The American chestnut, Castanea dentata, was undergoing selection and development as a nut tree in the U.S. just prior to the introduction of the chestnut blight fungus. The fledging orchard industry, centered in Pennsylvania, was decimated by the disease around 1910. The blight resistant Japanese chestnut, C. crenata, had been introduced in the 1800's but the later introduced Chinese chestnut, C. mollissima, proved to be better adapted to conditions

in the East. Large quantities of Chinese chestnut seed and seedlings were distributed by the USDA in the 1920's and 1930's. Cultivars were selected from small established orchards. To date no large orchards of clonally propagated trees have been established.

Available yield data are largely from small plantings of seedling trees located in the Southeast. In Maryland 19 2 year old trees planted in 1930 began to bear 4 years later. At age 16 they produced 40 lbs per tree, equivalent to about 2,000 lbs per acre if planted at 30 ft x 30 ft spacing (Heming, 1944; Berry, 1958). Hardy (1948) received Chinese trees in 1926 and in the 1930's. The average annual yield per tree was 73 lbs by 1947, with one tree normally producing twice that amount. Actual annual yield averaged 1,000 lbs per acre, but it was assumed that with some selection and better management annual yields of 1,500 to 2,000 lbs per acre could be reasonably achieved in the Southeast. The cultivars Nanking, Kuhling, and Meiling were selected from Hardy's orchard. Jaynes (1967) estimated the annual yield of Chinese chestnut seedlings planted in northeastern Connecticut as varying between 500 to 2,000 lbs per acre per year. The yield of the Eaton cultivar, based on crops of the original tree in Connecticut, was estimated to be about 2,000 lbs of nuts per acre per year (Jaynes, 1970). Merrill and Crane (1961) evaluated five Chinese chestnut cultivars in a yield trial in southwest Mississippi. Significant yields began 7 years after planting. Selection A-7932, later named Crane, performed the best and yielded 28, 36, and 29 lbs per tree in the 9th, 10th and 11th year, respectively.

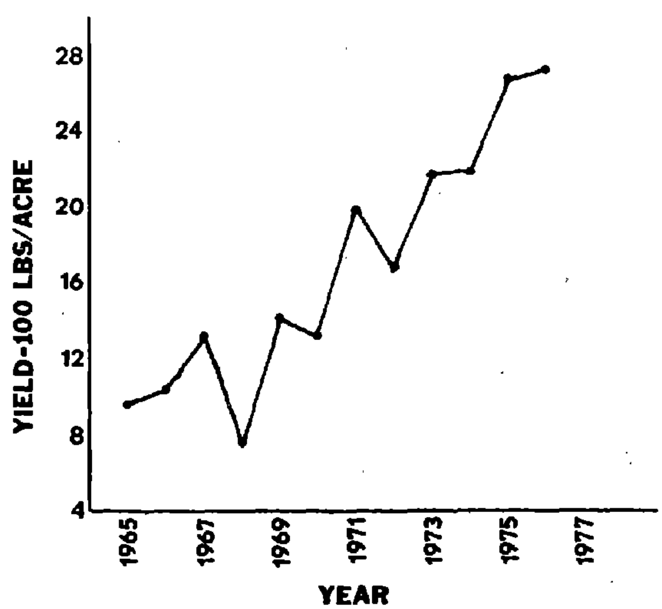

Figure 1. Annual yield of a 20-acre seedling Chinese chestnut orchard for 12 years, Cordele, Georgia. Trees were 15 years old in 1965 (Payne, 1979).

Payne (1978) reported yield for a 20-acre seedling Chinese chestnut orchard in Georgia that was 15 years old in 1965 (Figure 1). After 20 years, yields were 2,000 to 2,800 lbs per acre per year. Information for C. sativa in Europe indicates that selected cultivars with good land and management could yield up to 4,000 lbs per acre per year, but actual yields on the upland soils typically average 1,000 lbs per acre.

Filberts

Commercial orchards in the Northwest have produced 5,000 lbs of nuts per acre per year, but the average is slightly less than 2,000 lbs per acre per year. Filberts grow reasonably well in the East and have been planted extensively, but there is little or no information on potential yields. Filbert bud mite, eastern filbert blight, and lack of hardiness of the catkins are all serious problems. The nuts are even more susceptible to predation by squirrels and birds than are those of other nut trees.

Hickories

Pecan, Carya illinoensis, does not fruit reliably in most of the northern U.S. Good pecan yields in the South are 1,500 to 3,000 lbs of nuts per acre per year (McEachern, 1978). In the northern reaches of its range, Missouri, Illinois, and Kentucky, yields are less. Other hickories, namely, shagbark, C. ovata, and shellbark, C. laciniosa, are hardy and fruit much farther north than pecan. Numerous cultivars of shellbark and shagbark have been selected but virtually no reliable production figures are available. Bowers (1960) reported on the 37-year production of a single 3-ft diameter, 90-to 100-ft tall shellbark hickory in West Virginia. It produced a crop on alternate years, averaging 10 bushels of nuts for the on years or a total of 185 bushels over the 37-year period. Weschche (1964), who experimented with over 50 cultivars of hickory in Minnesota was uncertain as to potential yield per acre. He did state that hickory trees are at least as productive as black walnuts in kernel but not in pounds of unhulled nuts.

Persian Walnuts

Culture of the Persian (English) walnut, Juglans regia, began in California and Oregon with selections from Spain and France. In California, under good growing conditions, selected cultivars can yield close to 4,000 lbs of nuts per acre per year: average annual production is just in excess of 2,000 lbs per acre (Reed, 1977). Hambleton (1974) estimated, from trees in a small planting in southern Ontario, that yields of 1,000 to 2,000 lbs of nuts per acre per year could be obtained. Yield of a 2-acre planting consisting of 100 trees and 32 cultivars in northwestern Ohio (Weaver, 1980) is given in Figure 2. During the past 11 years yield has averaged 986 lbs per acre per year. Variation in production was reportedly highly dependent on the weather, especially late spring frosts and rain-humidity conditions at the time of pollination. Many cultivars have been

selected throughout the Eastern United States, but replicated varietal trials are lacking.

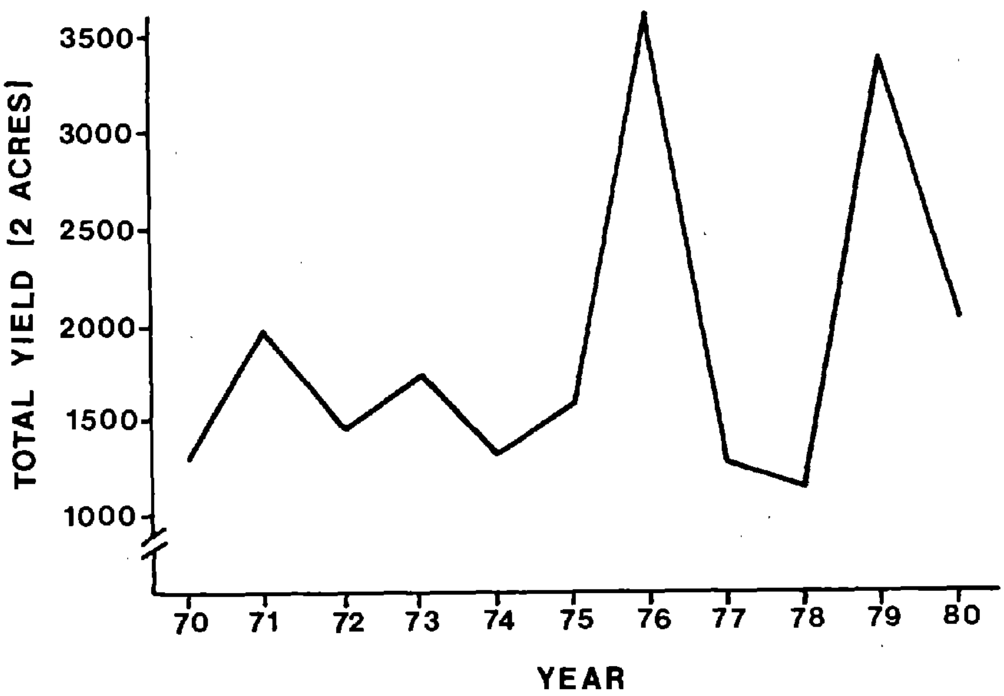

Figure 2. Annual yield of Persian walnuts from a 2-acre planting, Maumee, Ohio. Average annual yield per acre was just under 1,000 lbs (Weaver, 1980).

Black Walnuts

The wood of black walnut, Juglans nigra, is the most valuable of all hardwoods grown in the U.S. It is also the only major nut crop that is harvested almost exclusively from wild trees rather than cultivated. The annual crop that enters the commercial trade is about 50 million pounds of in-shell nuts, or about twice that of filbert production, but the dollar value is less. Considerable information on growing black walnut for wood and nuts is available, much through research and workshops promoted by the U.S. Forest Service at Southern Illinois University, Carbondale, Illinois. Actual and potential returns for a 98-year-old planting are given in Table 1 (Oldham and Heflin, 1975). Similar tables estimating value for growing other crops (multicropping) along with black walnuts planted for wood and nut production are available (Foster, 1979. Kurtz et al, 1978. Naughton, 1970. Thompson, 1976).

Table 1. Actual and potential returns on a black walnut plantation.

Stand description	Rotation age	Value per acre	Value per acre per year
Perrin plantation, 1965	88	$ 1,439	$ 16.35
Perrin plantation, 1975	98	3,950	40.28
Stand like best tree in Perrin plantation	98	6,300	64.37
Intensive management, logs only	70	18,928	270.00
Intensive management, logs and nuts	70	25,144	359.00

Rotations of 60 to 80 years are required to maximize wood production. The natural variation in seed characteristics and seed yield of individual trees has been well documented (Zarger, 1946; Zarger et al, 1969). Since 1881 numerous cultivars, such as Thomas, have been described for their nut qualities, but there is little yield data to evaluate their performance in the same or different areas. Orchard yields for successive years are unavailable. MacDaniels (1979) has evaluated nut quality of many cultivars.

Other Species

Butternut, _J. cinerea_, and Japanese walnut, _J. ailantifolia_, have also undergone selection and propagation among the amateurs. Yield data are not available. Butternut naturally occurs further north than most other nut trees and is therefore a likely candidate for attention in the colder areas.

Other native nut trees have received less attention than those mentioned. A few cultivars of beech have been selected and named for their nut size. Gysel (1971) found that native beech in Michigan over a 10-year period were comparatively poor and erratic nut producers. On a relative scale, nut production was a failure for 2 yrs, low for 4 yrs, intermediate for 3 yrs and high for 1 yr.

Acorns are, of course, the most abundantly produced native nut. Christisen (1979) reviewed the acorn production of oaks, especially in light of their food value to wildlife. Native tree production varied from just a few pounds to 800 lbs per acre per year. (More information on the oak-acorn situation can be found elsewhere in this symposium.)

Other Attributes

In addition to the nutrient value of nut kernels there is the obvious value of the wood as fuel or timber; however, wood from most large nut trees has more value as lumber, veneer stock, or in constructing furniture or crafts. Black walnut commands the highest price but the other walnuts, hickories, and chestnut are also in demand.

The husks and shells of nuts grown in the North may prove to have special value. Commercially only about 7 lbs of good kernels are recovered from each 100 lbs of hulled, dry, black walnuts. It is the resale value of the shells that helps make the harvesting and cracking of the nuts for the kernels economically feasible. Until recently pecan shells created a waste disposal problem. Like walnut shells they are now used in drilling muds, glue extenders, mulches, abrasive cleaners, cattle roughage, molded furniture, and even plastic (Anon., 1979). Keys and others were issued a patent (#4,098,765) in 1978 for a process to make a Bakelite form of plastic from the phenols extracted from the shells and packing material of pecan. The fruit characteristics of four species of nut trees are given in Table 2.

Table 2. Fruit characteristics of pecan, black walnut, filbert and Chinese chestnut, dry weight basis (Sparks 1975,1980).

	Shell		Kernel		Shucks		Total	
Fruit	wt g	% total wt	wt g	% total wt	wt g	% total wt	wt g	Kernel % of nut wt
Pecan	3.1	31	4.1	41	2.8	28	10.0	57.5
Bl.walnut	15.7	48	5.8	18	11.0	34	32.4	26.9
Filbert	1.9	54	1.0	28	.6	18	3.5	34.0
Chestnut	1.0	5	4.4	22	15.0	73	20.4	80.7

Table 3. Food Value of Nuts (Taylor and Turner, 1967)

Nut	Water %	Protein %	Fat %	Carbohydrates %	Calories per ounce	Crackout %
Almond	5	21	55	14	190	55
Beechnut	4	22	57	13	200	60
Butternut	4	28	61	3	215	15
Chestnut, fresh	43	6	6	41	70	85
Chestnut, dry	6	11	8	70	115	77
Filbert	6	13	64	5	215	62
Hickory nut	4	15	67	11	220	38
Pecan	3	12	71	8	225	50
Walnut, black	3	30	58	6	195	26
Walnut, English	3	18	61	14	205	42

The absolute and relative weights of kernel, shell, and shuck vary greatly among the species as does the oil, protein, and carbohydrate content (Table 3). Because the shells are removed from the planting area, and the husks as well for black walnut, Sparks (1975, 1980) analysed the kernel, shell, and shuck for their chemical composition (Table 4). Note that the dry shucks (husks) of black walnut, filbert, and pecan contain more than 1% nitrogen and up to 8% potassium.

Table 4. Elemental concentration of pecan, black walnut, filbert, and Chinese chestnut, dry weight basis (Sparks 1975,1980).

Fruit		N%	P%	K%
	shell	.4	.1	.3
Pecan	kernel	1.2	.3	.4
	shuck	1.1	.2	7.8
	shell	.5	.02	.4
Bl.walnut	kernel	4.6	.5	.7
	shuck	1.4	.2	3.2
	shell	.5	.02	.2
Filbert	kernel	3.4	.4	1.2
	shuck	1.3	.2	2.8
	shell	.6	.02	.1
Chestnut	kernel	1.6	.1	.7
	shuck	.8	.04	.6

Difficulties

As a food crop nut trees do not appear to be economically viable in the North, at least as measured in the traditional yardstick of net profit per acre. The evidence for this is the lack of expansion or actual failure of orchards established rather than detailed economic analysis. Crops like blueberries, raspberries, and Christmas trees, which can also be grown on hilly and even uncultivated land, have given quicker and higher returns. None-the-less, actual numbers of nut trees sold for wildlife, forest, and home use has apparently increased (Christisen, 1978).

I summarize some of the problems faced by a potential grower of nut trees in the North especially on small farms with less than the best farm soils.

1) The best cultivars for production, cross-pollination, and pest resistance are unknown and untested.

2) Clonally propagated trees of selected cultivars are expensive

and not readily available.

3) Economical controls of common insect, disease, and animal pests are unknown or untried. Effective pesticides may not be registered for the crop. Research by the public and private sector is not focused on crops that are of minor economic importance.

4) Expertise on soil management, pruning, fertilizer, and other cultural practices is often not available locally.

5) Efficient harvesting techniques have not been developed.

6) Marketing of the crop may be difficult.

7) Time from planting to first nut harvest may be 10 years, or even longer with trees like shellbark and shagbark hickory.

No one who has been involved in the management of a large monoculture, for example 1,000 acres or more of pecans, would suggest that it can be done without considerable skill and knowledge of the crop, land, weather, market, etc. Yet, when we speak of small farms we often state or imply a diversity of crops, assuming somehow that pest problems will be less and production will be equal or better to that in a monoculture system. The opposite is more likely true. The diversified farmer may have to contend with the sum of all the problems encountered in each of several separate monocultures. Each crop has its own set of problems regardless of the size of the planting. Indeed, small plantings may invite special problems. Insect, fungal, and bird and mammal predators, which move in from the perimeter of the planting, can much more severely impact the percent of crop lost in a small than in a large planting. Witness the edge effect of gypsy moth larvae damage on a Christmas tree planting, racoons on a cornfield, or squirrels in a nut orchard.

Evaluation

Nut trees are not economically competitive with other crops in the North in the usual sense, but they have been selected, propagated, and grown non-commercially for years and the interest and enthusiasm in them is increasing. Because nut trees produce valuable food and fiber and because they are grown commercially in other areas, we usually evaluate them against traditional crops. Perhaps we should compare their worth with lawns, ornamentals, and shade trees, which are also valuable but in ways that are more difficult to quantify. They produce no consumable product, yet that does not make them any less valuable or even any easier to grow and maintain in good condition. In some situations the amenity values of nut trees may be equal or greater than the cash value.

We should be careful not to delude ourselves and others to suggest that presently unmanaged land (woodland and abandoned farm land) can be planted to food bearing trees and thus make it productive

without considerable inputs. As soon as we plan to increase the level of investment enough to plant and manage nut trees then we should compare what could be done with other crops with similar investments of time and money.

The articulate evangelizing of J. Russell Smith and others have focused attention on nut trees. Intuitively, many of us feel that nut trees have a place in the North. However, we have tended to romanticize the economics, overlook the intangible values, and ignore the vast chasm of cultural information needed to make intelligent decisions.

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UTILIZATION OF MESQUITE (PROSOPIS SPP) PODS FOR ETHANOL PRODUCTION

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Abstract

Mesquite (*Prosopis* spp) is a nitrogen fixing, salt-tolerant, arid land shrub or tree which occurs on 72 million acres of semi-arid marginal land in the southwestern United States. Clonal *Prosopis* selections have been made for pod and woody biomass characters after evaluation of 80 accessions representing 13 species in four field plantings. Experimental mesquite strains show promise as an energy crop both from production of woody biomass and from fermentation of 36% sugar content pods.

Introduction

The genus *Prosopis* contains 44 species of nitrogen fixing woody shrubs and trees indigenous to the subtropical semi-arid and arid regions of Asia, Africa, and North and South America (Burkart, 1976). In Asia, *P. cineraria* is used to increase the fertility of the soil for pearl millet crops (Mann and Shankarnarayan, 1980). In East Africa, introduced *Prosopis* species are being used to control desertification, to provide woody biofuels, and to provide pods for livestock food (Felker, unpublished observ.). In Mexico in 1965, 40,000 t of mesquite pods were reported in agriculture statistics handbooks for use in the cattle feed industry (Lorence, 1970). In Chile, thousands of hectares have been planted in *Prosopis tamarugo* to provide forage for sheep in the rainless Atacama salt-desert (Salinas and Sanchez, 1971).

In the United States, mesquite was the staple of life for Indians in southern California and Arizona (Felker, 1979). Today mesquite is an important bee forage for honey production in Arizona (B. Stockwell, pers. commun.). Large cut, dried, and planed mesquite wood sells for luxury prices of $4-5.00 per board foot (Mouat, pers. comm.). Mesquite firewood commands premium prices of over $200 per cord in metropolitan areas such as Houston, Phoenix and Los Angeles. For two winters, residents of the economically depressed Texan-Mexican border town of Crystal City, Texas have used mesquite wood for winter heat after being cut off from natural gas supplies. The only U.S. government effort on mesquite for the last 35 years has been eradication of mesquite from rangeland where annual returns from cattle grazing are $2 per acre per year (Herbel, 1979).

Current Research Activities

Prior to U.S. Department of Energy (DOE) funding at UCR, no program existed in the United States to develop the potential of mesquite on arid lands. Since award of the DOE grant in 1978 we have made progress in the following areas:

1) Germplasm collection -- Over 600 single tree *Prosopis* selections of 14 species have been made that include genetic stock from Africa and North and South America.

2) Cultural practice development -- Mechanized techniques have been evaluated and improvised to separate mesquite seeds from sticky high sugar content floury pericarp. Insect control measures have been developed for field and greenhouse work. Herbicide treatments have been found that are effective on established seedlings on fine textured soils.

3) Biomass screening trials -- At UCR 32 accessions are being screened for woody biomass in field trials at 3 soil moisture levels. In the California Imperial Valley, 55 accessions are being screened for woody biomass production under drought/heat stress conditions. Nearly a 100 fold range in biomass productivity among accessions has been observed. Many of the non-productive accessions are from the rangelands of southwestern USA indicating substantial improvement is possible. Replicated small plot first-year biomass production was 14 oven dry tons per hectare.

4) Biomass estimation -- Mesquite harvest, dry matter determinations, and regression equation development have been performed to allow estimation of dry biomass for stem diameters in the 0.2 cm to 7.5 cm range.

5) Evaluation of mesquite water needs -- The first two years'data from a differential irrigation treatment study indicate that mesquite growth is greater if irrigated when the soil water potential at the 18" depth is minus 2 to 5 bars than when irrigated at more typical and frequently irrigated water regimes of minus 0.6 bars.

6) Develop vegetative propagation techniques -- Numerous hormones, hormone concentrations, quick-dip solvents, rooting media, and fungicides have been evaluated in an attempt to root mesquite cuttings (only negative reports of rooting mesquite cuttings are in the literature.) Cuttings typically are greater than 50% rooted if taken from greenhouse grown stock but are frequently less than 1% rooted when taken from mature field trees.

7) Examine mequite cold and frost hardiness -- Thirty accessions including some expected to possess good frost tolerance and some high biomass producing South American accessions were planted at 5,000 ft elevation where minimum temperatures of 22°F occur from December through March. A high cold/frost induced mortality occurred at the site. Fifteen of the largest (fast growing) trees which survived have been dug up, and potted to serve as sources of cold tolerant germ plasm.

8) Investigation of nitrogen fixation -- Thirteen *Prosopis* species were inoculated with mesquite rhizobia, grown for 8 months on a nitrogen free medium, and assayed via acetylene reduction for

nitrogen fixation. All accessions nodulated, reduced acetylene, and grew on nitrogen free media, thus confirming mesquite's nitrogen fixing capabilities.

9) Salinity tolerance -- Greenhouse solution culture experiments with 6 *Prosopis* species found a Hawaiian species, *P. pallida*, and a Chilean species, *P. tamarugo*, that grew and fixed nitrogen at salinities equivalent to seawater. Other plants are known that are capable of growing on seawater but this is the first terrestrial plant which can grow and fix nitrogen on seawater.

In addition to the above mentioned technical developments, overseas development work on *Prosopis* has been carried out in the Sudan with United Nations Development Program (UNDP) support; in Chile with CORFO support; and work is pending in Haiti with AID support.

Production of Alcohol from Mesquite Pods

Due to the strong current national interest in developing liquid fuels, the remainder of this paper will center on high sugar content mesquite pod production and resulting potential for alcohol production.

Mesquite Pod Production

Mesquite pod production data have been collected on two experimental plantings on the University of California, Riverside (UCR) campus and on a planting in the California Imperial Valley. The Riverside climate is cooler (daily July max of 34.6°C) than the Imperial Valley climate (daily July max of 41.7°C). In the Imperial Valley climate mesquite pod production occurs on much younger trees and biomass production is twice as rapid as in Riverside.

One hundred and ten UCR trees produced one 2.5 g pod the summer one year after transplanting, and 30.8 kg of pods the summer two years after transplanting (Table 1). As with most genetic characters in mesquite trees propagated from seed, pod production among the early producing accessions is quite variable. The accession with the highest pod production, *P. velutina* (0020), had trees with no pods as well as those with 4.8 kg (10.6 lb). Four of the 110 trees in these plots produced over half the pod production for the plot.

In an Imperial Valley planting of 1300 trees, 15 trees flowered, and six produced pods only six months after transplant (Table 2). Early pod production is important because it shows potential for achieving economic pod yields at early ages and because it would reduce generation time in breeding attempts to transfer desirable characters between accessions. Early pod production among *P. velutina* accessions 0020 and 0032 is consistent and noteworthy in both locations.

We have monitored pod production on three mature mesquite trees. One of these trees, a southern California native *P. glandulosa*

Table 1.

MESQUITE POD YIELD FOR TREES AT END OF THIRD

GROWING SEASON AT RIVERSIDE

Species	Accession Number	Origin	Avg. Yield/ Tree (grams)	Range in Yield/ Tree (grams)	Total Yield/ Accession (grams)
Prosopis velutina	0020	Arizona	1650	0-4797	8248
P. spp.	0025	Sonora, Mex.	1291	226-2913	5164
P. spp.	0032	Arizona	1267	268-4709	6337
P. glandulosa, var. torreyana	0001	California	996	0-3864	9957
P. velutina	0031	Arizona	75	0- 230	301
P. alba	0039	Argentina	44	0- 250	262
P. spp.	0030	Arizona	31	0- 115	125
P. spp	0027	New Mexico	26	0- 102	102
P. juliflora	0007	Unknown	10	4- 19	30
P. spp.	0029	Arizona	7	0- 21	21
P. spp.	0028	Texas	17	0- 17	17
P. chilensis	0010	Argentina			
P. alba	0163	S. America			
P. nigra	0038	Argentina			
P. nigra	0036	Argentina			
P. alba	0035	Argentina			
P. ruscifolia	0033	Argentina			
P. spp.	0026	New Mexico			
P. spp.	0024	Mexico			
P. spp.	0023	Arizona			
P. spp.	0022	Arizona			
P. spp.	0021	N. America			
P. chilensis	0009	Argentina			
			Unassigned:	281	
			Total	30,845 or 68 lbs	

During the summer months, these accessions are irrigated every 3 weeks by furrow irrigation. Plot yield previous year was 1 pod or 2.5 grams. Moisture content is approximately 10%.

Table 2.

MESQUITE FLOWERING AND POD SET SIX MONTHS

AFTER TRANSPLANT IN IMPERIAL VALLEY

Species	Accession Number	Origin	Number Flowering trees	Flowers/ Tree Avg.	Flowers/ Tree Range	Pods/ Tree Range
BIOMASS SECTION						
Prosopis velutina	0020	Arizona	5	8.6	1-20	0-6
P. spp.	0032	Arizona	8	7.5	1-12	1-7
P. glandulosa, var. _torreyana_	0246	California	1	1	-	2
P. velutina	0247	California	1	1	-	-
POD CHARACTER SECTION						
P. glandulosa, var. _torreyana_	0295	California	1	30	-	3
P. glandulosa, var. _torreyana_	0224	California	1	4	-	

There were 16 possible trees/accession that could have produced pods in the biomass section and 8 in the pod character section.

var. torreyana (0001), is located at the home of the late Mrs. Ruoy Modesto in Thermal, California. This tree is 7.5 m tall with two main trunks 25 cm in diameter at breast height. The tree is located in an area with less than 100 mm annual rainfall, with July daily maximum temperatures of 41°C and is located over a water table approximately 4 m from the surface. The tree in Mrs. Modesto's yard is not an unusually large or prolific bearing tree. It was chosen because it had been pruned to allow passage beneath its canopy which greatly facilitated pod harvest. Psyllid insects caused considerable leaf damage to this tree every year. Mistletoe had also severely infested this tree until the mistletoe was killed with chemicals in January of 1979. All the pods were picked from the tree in 1977 and 1978, while in 1979 and 1980 they were picked from the ground at weekly intervals after they had fallen. Pod yields at a moisture content of approximately 6% were 41 kg in 1977, 51 kg in 1978, 9 kg in 1979, and 41 kg in 1980. We attribute the low pod yield in 1979 to an extraordinarily early and severe frost (-9°C or 16°F) which damaged citrus, avocado, jojoba, palo verde, oak and guayule throughout the southwestern United States and northwestern Mexico.

A Prosopis alba (0166) tree planted as an ornamental and windbreak in the vicinity of the P. glandulosa var. torreyana (0001) was harvested because its progeny were the best biomass producers in Imperial Valley biomass test plots. This thornless evergreen tree had a canopy diameter of nearly 50 meters and provided 38 kg (6% moisture) of 14-cm-long, flat, curved pods. Only a small portion of the branches and nodes of this tree produced pods. For its size this was a light yield.

Chemical analyses from Bob Becker at the Western Regional Research Center indicated that the pod pericarp of a tree (0388) along the Colorado River 30 km north of Yuma, Arizona, had an exceptionally high (39%) sugar content. In August 1980, 73 kg (6% moisture) of these 30 cm long, 2.5 cm wide pods were picked up beneath this tree in five man-hours. This 17-year-old tree was located approximately 1.5 m above the Colorado River groundwater table in a row of five South American origin ornamental trees presumably from the same seed source. One of these trees was a good South American P. alba specimen in having tripinnate leaves, finely divided leaflets, no pubescence, absence of thorns, and short (12 cm long) flat curved pods. The tree we harvested (0388) had thorns of native mesquite, pod pubescence of P. velutina, leaf characters intermediate between P. velutina and P. alba, pods much larger than P. alba or P. velutina, straight and red-tinged pods like P. velutina, and the growth rate and tree shape of P. alba. We conclude P. spp. (0388) is a naturally occurring P. alba x P. velutina hybrid. Numerous examples of interspecific Prosopis hybrids occur in the literature (Burkart, 1976).

All these pod collections were made near a highway or dwelling where wild animals infrequently occur which would carry the fallen pods away. It is impossible to measure pod yields more than several

hundred meters from roads or dwellings because of animal use. One tree, located 100 meters from a paved road, was estimated to contain 30 to 40 kg of near ripe pods. When we returned two weeks later to collect the pods, not a single pod could be observed on the tree, on the ground, or in the vicinity of the tree. Small mammals had removed every pod.

In summary, in areas with shallow groundwater, mature tree yields around 40 kg are common and 72 kg yields are possible if located in very favorable circumstances. A reasonable yield goal for large managed mesquite tree orchards in areas with groundwater should be 50 kg (6% moisture) per year. On areas with groundwater present, the spacing would not be contingent on reducing water competition and standard orchard spacings of 7 x 7 m would be adequate for 200 trees per hectare and a 10,000 kg pod yield per hectare. On range situations where water is the limiting factor, a 4,000 kg/ha pod yield has been suggested (Felker et al., 1980).

An alternative to use of large trees at wide spacings would be to use short closely spaced trees to achieve larger yields in shorter times. If the three meter tall and wide, 2-year-old UCR trees which produced 4.8 kg of pods were on a 5 x 3 m spacing (667 trees/ha) they would have produced 3,200 kg/ha. A 5 m between row spacing would allow 1.5 m for each tree to protrude in the row and 2 m for small vehicular traffic. These high plant densities will not be possible with present South American x native hybrids because of the fast growth and large size.

Mesquite Pod Chemical Composition

Protein, fiber, and sugar contents are given for selected mesquite pod samples in Table 3. Pod samples from accession 0020, 0025, 0032, and 0001 were taken from UCR field trees whose yields are listed in Table 1. The three *P. velutina* accessions originally from southern Arizona and adjacent Mexico had similar early pod producing characteristics, but nevertheless had quite distinct pod chemical characteristics. The highest pod producer (0020) unfortunately had the lowest protein and sugar content. The highest sugar content (34%) was obtained from a southern California native, *P. glandulosa* var *torreyana*. These sugar contents are reflected in common names of velvet mesquite and western honey mesquite for *P. velutina* and *P. glandulosa* var. *torreyana*, respectively.

The second portion of Table 3 lists proximate values for only pericarp tissue because the seeds were saved for propagation. Accessions 0377 and 0372 were collected within 100 yards of each other in a desert where few differences in soil or environmental conditions were noted. Accession 0377 had a very sour-bitter taste while accession 0372 had a very sweet taste with no bitter aftertaste. Chemical analyses, courtesy of B. Becker at the WRRC, confirmed the taste differences but were unable to identify the sour principle in 0377. The difference in pod chemical

Table 3

PROXIMATE ANALYSES OF MESQUITE POD SAMPLES

Accession number	Species	H_2O (%)	Protein (%) N x 6.25	Fiber %	Sugar %
	Trees grown on UCR experimental plots (whole pods)				
0020	*P. velutina*	1.6	11	30	13
0025	*P. velutina*	2.1	14	19	28
0032	*P. velutina*	2.6	17	24	19
0001	*P. glandulosa* var *torreyana*	2.2	14	20	34
	Mature wild or ornamental southern California trees (Pericarp only - minus seeds)[a]				
0377	*P. glandulosa* var *torreyana*	8.1	8	30	13
0372	*P. glandulosa* var *torreyana*	8.3	5	23	41
0388	*P. alba* x *P. velutina* hybrid	4	10	19	40

[a] Seeds from these pods were saved for propagation use.

These chemical determinations performed courtesy of B. Becker, USDA-Western Regional Research Center, Albany, California.

characters between 0372 and 0377, located only 100 yards apart, illustrates the genetic diversity found in Prosopis and suggests that even higher sugar content pods might be located with a more thorough search. Accession 0388 had a more favorable pod composition than either 0372 or 0377 because of higher protein, lower fiber, and nearly equivalent sugar contents. Unlike 0372, accession 0388 had a slightly bitter-astringent taste which would not make it as acceptable as 0372 for human food. Pods of 0388 are nearly twice as long and wide as 0372 and 0377 or 0001. The larger sized pods would facilitate harvesting of fallen pods from mesquite trees.

The resistance of mesquite to leaf psyllid attack increases in the order P. glandulosa var torreyana, P. velutina, P. alba, suggesting that the 0388 hybrid will possess at least moderate resistance to psyllids. We have obtained several rooted cuttings of 0388 from several hundred attempted cuttings. Much higher rooting success rates can be achieved with "clean" greenhouse stock grown under optimal conditions for rooting of cuttings.

Estimation of resource potential for alcohol production from mesquite pods

Utilization of high sugar content pods from mesquite growing on extensive areas not in competition with agriculture or agricultural resources presents a significant and unrecognized alcohol fuels resource. Mesquite presently occurs on 72 million acres in the United States (Parker and Martin, 1952) where pod yields of 4,000 lbs/acre have been suggested as a reasonable goal (Felker et al., 1980). Mesquite pods have been reported to contain 20-30% sucrose and up to 60% nitrogen-free extract (carbohydrates) (Becker and Grosjean, 1980; Walton, 1923). We have found strains which contain 36% sucrose in the entire pod and 40 to 41% sucrose in the pericarp. If the malt process (starch hydrolysis) was avoided and the sugar fermented to alcohol at a theoretical conversion of 2 moles of ethanol per mole of glucose, one acre (4,000 lbs) would produce 111 gallons of ethanol per year. If the malt process were employed to complete fermentation of remaining pod carbohydrate, and the same ethanol yield of 2.6 gallons per 55 lbs were obtained for mesquite pods as for wheat, corn, or grain sorghum (David et al., 1978) one acre would yield 190 gallons of ethanol per year. Assuming the entire 72 million acres presently occupied by mesquite were used for mesquite pod production and fermentation, the upper estimate for alcohol production would be 0.89 million barrels/ day if the malt process were employed and 0.52 million barrels/day if only the sugar portion of the pods were fermented to alcohol.

The land area required for small commercial-sized ethanol production plants (1,000 barrels/day) could be contained in a circle of radius (maximum haul) of 6.8 miles, assuming a conversion of 2.6 gallons of ethanol per 55 lb of pods and a 4,000 lb/acre pod production. Twelve percent of the land area in this 6.8 mile

radius would be devoted to high, woody, biomass-producing mesquite varieties to provide energy for the distillation process. The calculated area (12% of total) required for distillation energy assumes production of 4,000 lbs of oven dry wood per acre per year, 8,000 Btus per pound of wood, and an energy requirement of 25,000 Btus/gallon to distill the alcohol.

An alcohol production of 0.5 to 0.9 million barrels/day represents 20-30% of President Carter's synfuel goal of 2.5 million barrels/ day (Anon., 1974). Data supporting these contentions for alcohol production are certainly tenuous. Nevertheless, the possiblity of obtaining such large quantities of alcohol fuels from what at first appears to be an environmentally attractive technique and one that is not in competition with agricultural resources deserves further investigation.

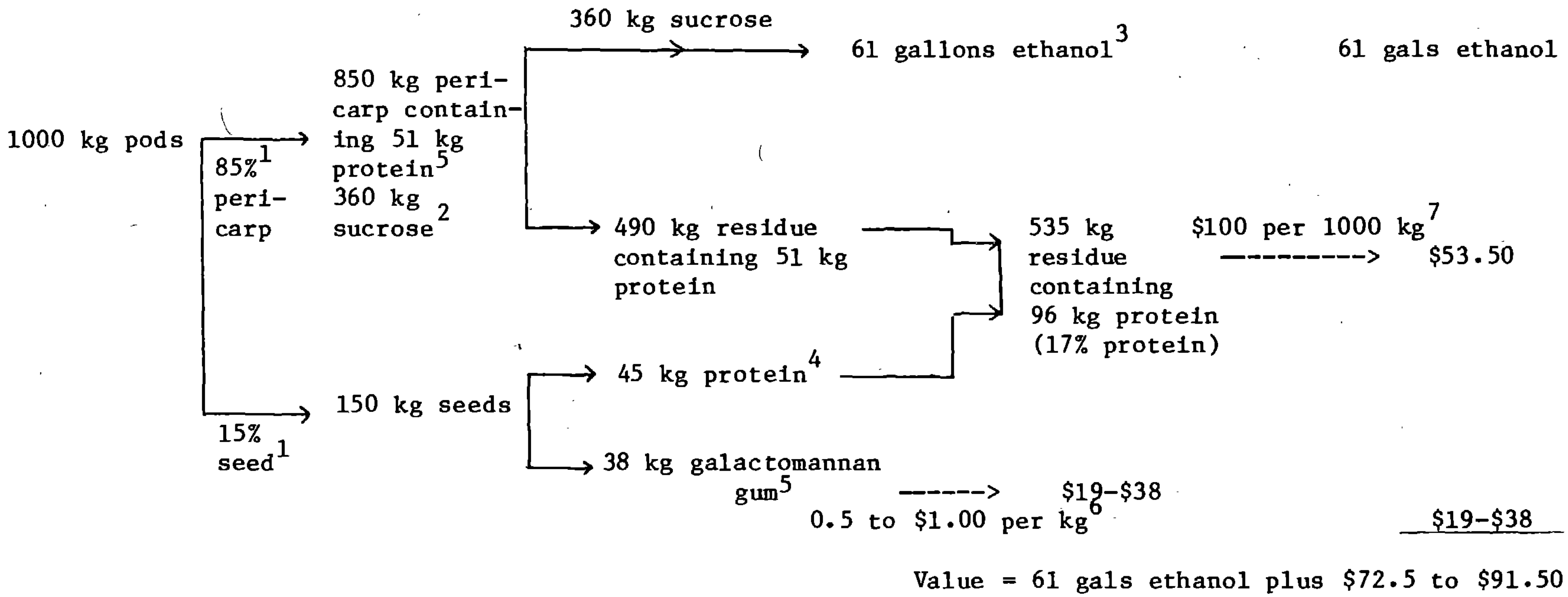
<u>Fractionation and use of mesquite pod sugar, protein, and gum</u>

Mesquite pods should be fractionated into sugar, protein, and gum fractions to realize their full economic potential (Figure 1). After the pods have been dried at 52^{o}C for several hours they can be ground in burr type mills which release the seeds from the sugar containing pericarp. Seed cleaners are available, such as Clipper cleaners from Burrows Equip., Chicago, Illinois, which perform good separation of the seeds and floury pericarp. The floury pericarp of a selected <u>Prosopis</u> strain contains 41% sucrose (Becker and Felker, unpublished observations) and it is this fraction that would be subjected to fermentation. The seeds contain approximately 30% protein and 25% galactomannan gum (Becker and Grosjean, 1980). Becker, at the USDA Western Regional Center, believes it will be possible to separate the protein from the gum with a dry milling process. The seed protein fraction could be mixed with the pericarp residue after fermentation to be sold as livestock feed (similar to dry distillers grains). (Neither seeds nor pods contain cyanogenic glucosides). Galactomannan gums are found in a variety of industrial, cosmetic, and food uses (Whistler, 1973). A 1% aqueous mesquite gum solution has a viscosity of 3,000 centipoise (Figueirda, 1975) and compares favorably with viscosities for equivalent carob and guar solutions of 100 and 4,200 centipoise respectively (Whistler, 1973). Prices for mesquite seed gums could be expected to be similar to carob seed gum prices which ranged from $0.62 to $1.11 per kg in 1970 (Whistler, 1973). As can be seen in Figure 1, mesquite seed gum could be a valuable byproduct of alcohol production. The world production of carob seed gums was 15,000 tons in 1970. Pedigree Petfoods, one of the largest European pet food manufacturers, is currently evaluating the quality of mesquite seed gums.

<u>Economics of mesquite wood and pod production</u>

Updated cost estimates for mequite wood and pod production from our 1979-1980 annual report are given in Table 4. These projected costs are for a hypothetical, large-scale, southwestern United States

Figure 1
Returns from mesquite pod fractionation



1 Becker and Grosjean (1980)

2 Felker and Becker
Unpublished analysis for selected mesquite variety

3 Assumes theoretical conversion of 2 moles alcohol per mole of glucose

4 Assumes Becker and Grosjean (1980) value 30% protein in seed

5 Assumes Becker and Grosjean (1980) value of 25% galactomannan gum in seed.

6 Values from Whistler (1973) page 326 for botanically related carob seed gum

7 Substitute value equivalent to Dry Distillers grains

Table 4
PROJECTED COSTS FOR MESQUITE WOOD AND POD PRODUCTION

	Cost per rotation per acre	
	Woody biomass 10 yr Rotation	Pod production 60 yr Rotation
Land lease ($10/acre /year)	$100.00	$600.00
Site preparation (herbicides, bulldozing & discing)	178.50	178.50
Seedling costs @ $0.15 each 265/acre pods, 436/acre biomass	65.40	39.75
Planting costs (1,000 trees/hr with mechanical transplanter + 3 man crew) @ $0.031 each	13.50	8.21
Insecticide application: 6 Sevin applications/yr @ $6 each/yr. Insect resistant biomass varieties do not require insecticide	——	2,160
Fertilizer costs: 100 lbs P, 300 lbs K, 50 lbs S per 10 year	67.00	402.00
Pruning costs	n/a	unknown
Harvesting costs @ $12 per OD ton for woody biomass using Texas Tech prototype x 20 tons	240.00	unknown
Total first rotation	684.40	4,602.46
Product	20 tons wood	100 tons pods
Unit cost	$ 34.20/ton $ 20.00/ton in 1st coppice rotation	$ 46/ton and $25/ton if insect resistant varieties could be used

This analysis assumes a south Texas location receiving 20" annual rainfall where brush must be cleared from site prior to planting. Pod production can start as early as the second or third year. No pod production was assumed til year 10 when a yield of 4,000 lbs pods/acre/year was assumed for 50 years. A pod production of 10,000 lbs/acre/year might be possible on a river bottom site with unlimited groundwater.

mesquite biomass farming operation receiving 20 inches annual rainfall. Seedling costs, herbicide applications, and insecticide application are based on our current empirically developed procedures. It is assumed the site is occupied with brush requiring herbicide applications, bulldozing, and discing prior to transplanting. (Credits from harvesting mesquite lumber, cordwood, or chips could be substantial but are ignored in this analysis.) The land lease of $10 per acre is that reported by Scifre (1973) as return to cattle ranchers. Herbel (1979) has reported a lower figure of $1.60 per acre as net return for cattle grazing. Fertilizer costs are computed to replace the nutrients removed in the biomass. Woody biomass harvesting costs of $12 per oven dry ton ($6 per green ton) are taken from values suggested for a Texas Tech prototype harvester (Burzlaff and Ulrich, 1979). Presumably harvesting costs would be less for larger and/or commercial harvesters. We have achieved woody biomass production levels of 7 dry tons/acre in small (1000 ft^2) replicated plots the first year under partial irrigation (3 ft) which are considerably in excess of the 2 ton/ acre production levels suggested in Table 4. We have chosen lower production levels because with few exceptions partial irrigation will not be possible on the 72 million acres of semi-arid land presently occupied by mesquite and because of a desire to conservatively estimate yields.

If mesquite were to be grown in areas where brackish irrigation water (electrical conductivity less than 15 mmhos/cm) were available for partial irrigation or on a riverbottom where the roots could tap umlimited groundwater, production levels in excess of the first year's production of 7 dry tons/acre should be possible. Such lands will have higher rental costs and will allow shorter (3-5 year) rotations.

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THE CULTURE OF CAROB (CERATONIA SILIQUA L.) FOR FOOD, FODDER AND FUEL IN SEMI-ARID ENVIRONMENTS

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Carob is indigenous to the Mediterranean region and has been cultivated there since ancient times. The exact center of origin of carob is uncertain, but it is generally placed in the eastern Mediterranean, either in Palestine (30), along the coasts of southern Turkey and western Syria (9), or in the southern Arabian peninsula (66). Further controversy surrounds Biblical references to the sweet fleshy fruit, believed to be the "husks"referred to in the parable of the Prodigal Son, but perhaps not the "locusts" consumed by St. John (9,30,62). First recorded mention of carob cultivation dates from the 18th century B.C. after the tree was introduced to Egypt from Palestine or Syria (17). Carob is believed to have been spread by the Greeks to Greece and Italy, and then by the Arabs along the coast of northern Africa and to Spain, from where it further migrated to Portugal and southern France (5).

Written reports of its early uses reflect the importance of carob in the lives of Mediterranean peoples. In ancient Palestine, grafted carob trees were interplanted with olives, grapes or barley (30). Beyond its traditional uses as a palatable fodder for livestock and as a survival food for the poor, the pods were distilled into wine and brandy and processed for tannins (30). Due to their consistent size, weight and hardness, carob seeds were used as weights on shopkeeper's scales and ground into powder for glues and gums (35). The tree itself also yielded decorative hardwood, firewood and leaves for writing paper (30).

History of Carob in California

Long after its economic importance became well established in its native range, carob was first imported to the U.S. in 1854 by the U.S. Patent Office which distributed seedlings of different varieties for trial in several southern states (62). The exact date of its introduction to California is uncertain, but seeds were received from the Patent Office by a university experiment station in Los Angeles County in 1885. A few years later, the tree was widely planted by the Santa Fe Railroad as an ornamental to landscape its new passenger stations (14).

However, not until 1922 did the first California carob "boom" begin.

A group of real estate promoters planted 1000 acres of carobs near Riverside and offered for sale five acre parcels and assistance in maintaining the young trees. Promises of quick profits and self-sufficiency were doomed to fail because their attempts at budding to good varieties were largely unsuccessful so that only unproven seedlings were left to mature. Final collapse of the venture came when the land, known as the "Cornell-Holmes" tract, was condemmed for a new reservoir to serve the growing cities of southern California. This episode served to inhibit further interest in carob for years to come (14,62).

It was not until the 1940's that interest revived in carob as a potential commercial crop for California. El Molino Mills, then as now the largest processor of carob for food in the U.S., became interested in the high sugar pods as a chocolate substitute and began importing "kibble" (crushed, deseeded pods) from Cyprus. Increasing interest in the crop initiated a long-standing cooperation between J. Elliot Coit, plant scientist, and Walter Rittenhouse, M.D. In 1949, the pair launched a thirty year carob varietal testing program on 11 acres in San Diego County by planting seedlings of the best foreign varieties and a selection of promising seedlings from around the state. So began the "Carob Crusade" (14,62).

Their efforts at promoting the crop by compiling information on carob varieties and culture and the availability of budded stock of the best varieties from several nurseries, resulted in a number of plantings of mostly five acres or less in southern California. It eventually became clear, however, that no small California grower could ever hope to compete with foreign carob, being imported in the late 1950's by El Molino at a delivered price of $0.05/lb. (62). Industrial interest in fostering a local supply of carob evaporated with the peace settlement on Cyprus (62).

Many of these early plantings were lost to rabbit or deer damage or otherwise abandoned. Scattered small planting still exist today on horse ranches in southern California (62,64). The only California grower to ever make a commercial sale of carob tended a small plantation in the low desert near Palm Springs. The trees responded to copious irrigations and warm temperatures by growing rapidly and producing heavily. Sale of a small quantity of processed carob to El Molino was made possible by a small-scale kibbling machine that he devised (62).

The latest California "Carob Crusade" has now subsided with the passing of Drs. Coit and Rittenhouse. Their demonstration orchard, previously held in trust by a mortgage bank, has been sold and is now in the process of development for housing. However, a few of the best varieties in the collection were transplanted to the nearby Quail Botanic Garden (25). While they later acknowledged the economic constraints to profitable carob culture in California, Coit and Rittenhouse hoped that their varietal testing efforts would provide the groundwork for any possible future exploitations (14).

Present and Potential Centers of Production

Carob is produced commercially and cultivated as an indigenous crop throughout the Mediterranean. Major producers are Cyprus, Greece, Italy, Spain, Portugal, Tunisia, Algeria and Israel (11). Although its present production is declining, Spain is the largest producer of carob (374,000 tons in 1973) and almost all of the crop is consumed domestically by farm animals (23). Italy ranks second in production (160,000 tons in 1955-56), also with very little exported (52). Cyprus is the world's largest exporter of carob, its annual production remaining steady between 1946 and 1968 at 45,000 to 50,000 tons (18,52). Nearly all of the crop in the past has been exported to the United Kingdom and Western Europe, but sales are increasing to the U.S. and Japan (5,18).

The largest and only commercial carob orchard in the Western Hemisphere is located near Ensenada, Baja California, Mexico. Plantings were started in 1959 by Henri Badan, a Swiss immigrant. About 10,000 budded trees have been planted on 200 acres, but yields to date have been disappointing due to below average rainfall (34,62). A small kibbling machine is in use and the crop has mostly been sold for carob powder in Mexico (25,64). Several other countries are cited as potential commercial producers of carob. A modest potential for profitable carob growing exists in Australia according to a government survey, that also mentions imports of kibble from the People's Republic of China (22). Carob trees are also promoted for farm and village plantings in South Africa and India (32,44).

Principal Uses of Carob

In the Mediterranean, carob has historically provided fodder for goats, sheep and other livestock. The pods are claimed to have a feedling value equivalent to barley (11,38). Although high in total sugars (40-50% by weight), modern feeding trials show that carob contains only 1-2% digestible protein and is relatively low in metabolizable energy (3,21,63). Some researchers have postulated that condensed tannins account for observed depressions in growth of animals fed a high carob diet (40) while others believe this effect is due instead to its low energy content for which animals can compensate by increasing consumption (45).

Recent investigations have focused on the use of single-cell organisms to convert carob into a high-protein feed. Sugar solutions extracted from carob pods are an excellent substrate for culturing fungi such as *Aspergillus niger* and *Fusarium moniliforme*. The dried mycelium is a palatable and nutritious feed containing as high as 38% crude protein by weight (37,47,59). A relatively cheap and easy method suitable for farm or village-scale production of improved carob feed is by direct solid substrate fermentation. Culture of *Monascus ruber* or *Rhizopus oligosporus* on kibble produced a cake-like feed in three days containing 7% protein and 73-83% of the original sugars (42).

Beyond the traditional consumption of raw pods as candy by Mediterranean children, use of carob in processed confectionaries has greatly increased since the 1940's. Carob powder is used as both a substitute

and an extender for cocoa and chocolate, and for its own unique flavor, in candies, drinks, cakes and breads (5,9). As market prices of cocoa increase, less expensive carob powder can be used to replace up to 50% of the cocoa in baker's formulas (16). Carob syrup, produced by concentrating carob powder, is approximately 75% sugar by weight (11,46).

However, perhaps the most widely used carob product in the food processing industry is locust bean gum. The seed endosperm, chemically a monogalactan, is removed by a special process to produce the valuable gum (16). Also known as tragasol, the gum is utilized in a wide range of commercial processes and products, including paper, various foods as an emulsion stabilizer and thickener, textiles, cosmetics, pharmaceuticals, film emulsions, paints, polishes, ceramics and adhesives (5,11, 35). The seeds constitute about 10% by weight of the whole pod and one ton of pods yields an average of 35 lbs. of pure dry gum (11).

Due to its high sugar content and relatively low cost, carob was among the first horticulatural crops used as feedstocks for the production of industrial alcohol by fermentation in several Mediterranean countries (50). Alcohol from carob pods has been used as fuel in Italy, along with alcohol produced from other materials such as grape pomace, sugar beets, molasses and figs (51).

Carob is widely planted as an ornamental street tree in California and elsewhere; male trees are preferable since they preclude "litter" from pod fall. Its value as a drought-tolerant, low-maintenance landscape tree is limited somewhat by the large mature size and strong, invasive roots (5,11). Since it requires no cultivation, tolerates poor soils and is long-lived, carob is often recommended in suitable climate zones for reforestation, erosion control and windbreaks (5,11).

Botanical Description and Chemical Composition

Carob is the only species in the genus Ceratonia of the legume family (subfamily Caesalpiniaceae). The evergreen tree attains a mature height and spread of 30-40 ft. with branches extending to ground level. A slow to moderate grower in dry conditions, carob will reach 20 ft. in height in 10 years, but may live for more than a century. The large compound leaves each contain from one to six pairs of opposite, waxy leaflets (11,15). The taproot extends deep into the soil and has been traced down to 65 ft. Extensive lateral roots also grow near the soil surface, especially in heavier soils (62). Although a legume, nodulation and N-fixation are not yet proven in carob (1,11,18).

Carob is polygamous with the majority being dioecious (18). Some are monoecious, bearing both staminate and perfect flowers that may be mixed in the same infloresence and in varying proportions on the same tree from year to year (53). Flowers are borne in 1½-4 in. lateral racemes in leaf axils or at leaf positions on wood from two to six years old (10). Such infloresences arise from older branches year after year, eventually forming warty excresences on the bark (11,15). This bearing habit, different from most other fruit and nut species that bear only in the well-lighted periphery of the canopy, in part accounts for high

yields observed on some large trees.

In coastal southern California, bloom usually occurs from September to October, and in the inland desert areas, from July to September (11, 62). Pistillate flowers are primarily insect pollinated and develop into flat indehiscent pods 3-12 in. long and 1/4-3/8 in. thick at maturity (15,23). The sweet, pulpy pericarp contains 5-15 hard brown seeds. After pollination and fruit set, growth of the green pods is relatively slow over the first five months of development. They then elongate rapidly in spring, begin to turn brown by summer and finally ripen, near the coast, in October and November (11,15). Pod ripening may occur much earlier in the hot deserts, from June to July (62). Some varieties shed their pods naturally when mature, while others retain pods on the branches, along with the flowers for the next year's crop, for several months after ripening (11,15).

Chemical composition of carob pods differs widely with variety and climate. Analysis of deseeded pods from 36 different cultivars selected from the Coit-Rittenhouse demonstration orchard revealed the following percentages by weight at 10% moisture (62):

	Total Sugars	Crude Protein	Crude Fiber	Ash
Range	37.10-56.6	2.25-6.63	4.65-9.60	1.52-2.38
Mean	45.3	4.53	6.78	1.92

Pods also contain from 0.46 to 1.46% crude fat and 2.6% tannin by weight (6,45). Total sugars consist of about 75% sucrose, along with glocose, fructose and maltose in the ratio of 5:1:1:0.7 (36,39). Percentage of total sugars in the pods increases as they dry and mature. A rise of 20 to 50% dry weight total sugars was observed simultaneously with a decrease in moisture content from 80 to 15% fresh weight. This increase in total sugars begins after pod elongation ceases and corresponds with hot, dry weather during the fall ripening period (19).

Climatic and Edaphic Factors

Minimum temperature is the primary environmental factor that limits the range of carob. While varietal differences may exist, most mature trees will tolerate temperatures no lower than 20°F. Sustained temperatures of 15°F may cause complete defoliation from which only some trees recover (62). Immature trees are more sensitive, being severely damaged at about 27°F. Since bloom and pod ripening periods overlap, one or two year's crops may be destroyed if temperatures drop below 22-25°F during this critical period (18,53,62). Chance of frosts during fall and early winter in many parts of the state therefore effectively limits the commercial range of carob to the coastal and warmer inland areas of southern California. With some risk in colder winters or frost protection, the range could extend along the Colorado River and into southern Arizona (62). Despite the fact that carob may survive at elevations up to 2000 ft., the highest planting bearing reasonable crops

in California was at 1600 ft. near the coast (62). Fruit ripening requires 5000-6000 degree hours (23).

Although mature carob trees are quite drought tolerant and survive on deep soils with as little as 12-14 in. of annual percipitation, commercial production of good yields without supplemental irrigation requires a minimum of 20 in. annual rainfall (53,62). Protracted periods of high humidity during bloom and pod ripening often delay maturity and lead to molds, fermentation and insect infestation of the ripening pods. These factors decrease carob's commercial productivity along the coastal fog belt of southern California (11,62).

Carob is less exacting as to soils than most tree crops except pistachio (53). It grows in almost any soil type that is well-drained and aerated, including sands, clay loams, limestone, alkaline or moderately acid soils. Carob thrives even on rocky or stony slopes, provided its deep taproot can penetrate cracks to find adequate soil (11,18,53,62). In deep soils of moderate to high fertility, carob may produce abundant vegetative growth and reduced crops of pod lower in sugar than on poorer soils (23). Carob is thus well-suited to growth on marginal lands where few if any other agricultural crops will survive without intensive care.

Propagation

In the Mediterranean, carob has historically been grown to only a limited extent in well-planned orchards and if then, usually in combination with intercrops such as olives, grapes or barley (18). It is more common as a wasteland crop, occupying the rocky, untillable slopes above the irrigated terraces or plains. Wild seedlings are budded <u>in situ</u> to good varieties and the pods harvested directly by livestock grazed beneath them (11,23,39). However, commercial plantations have expanded in Israel and other countries (31,53).

Propagation of carob seedlings begins by first soaking the seeds in concentrated H_2SO_4 to break down the hard endosperm (41). Treated seeds are sown in deep flats of soil mix and transplanted at the second true leaf stage to deep tubes made of asphalt roofing paper 4 in. in diameter and 18-24 in. long (41). These bottomless containers should be suspended off the ground on screens to allow air pruning of the roots or at least moved periodically to prevent root escape (11). Young carob seedlings in containers are often very slow growing and may require two years to attain salable size as commercial nursery stock. Experimental applications of monthly foliar sprays of gibberellin accelerated the vegetative growth of young carob seedlings (29).

Once containerized seedling rootstock has attained at least ¼ in. diameter, it can be successfully budded to improved varieties by the flute or ring methods (33,62). These techniques employ a special knife with two parallel blades set 1 in. apart to remove identical sections of bark from both stock and scion. Pieces of scionwood containing the bud are fitted to the root-stocks and secured with plastic tape.

T-budding is also fairly successful. Best time of year for budding is in spring, as soon as the bark is easily removed or "slips" (33,62). Seedlings may be budded by these methods after planting in the field and mature trees grafted by the saw-kerf or notch methods. Propagation by air layering in late summer is also possible (33,62). Hardwood cuttings are generally difficult to root, but pretreatment with acid prior to applying IBA may help promote rooting of cuttings (43). Nonetheless, seedling rootstock is preferred since a deeper taproot develops (11).

Orchard Establishment

Carob trees cannot be easily handled as bareroot stock and thus are planted out directly from containers with as little disturbance to the root ball as possible (11,62). Preferably planted in early spring, trees are spaced 30-35 ft. apart in rows along the contour for a density of 40-45 trees/ac. (10,11,53). At least 5% of the total area should be planted with male trees of varieties known to produce a high percentage of viable pollen in order to insure adequate pollination of female and hermaphrodite trees (59,62).

Staking and supplemental irrigation during the first two or three years of establishment are usually recommended (10,62). Basins around each tree are prepared and then filled by a water truck at planting and several times later in the first summer (10). Drip irrigation is an efficient means of irrigating young carobs, but the initial material and labor costs are high (41). In addition to drip irrigation of some trees, the Badan orchard in Mexico is irrigated with water "harvested" from the surrounding slopes. Runoff from winter rains is channeled into broad "V's" dug into the hillside above each row (41). Although erosion is a potential hazard, such micro-catchments and other techniques for "run-off agriculture" have been successfully used to grow crops such as pistachios, pomegranates, grapes, figs and almonds in arid environments (4).

Once established, carobs require relatively little maintenance. However, adequate weed control is vitally important when no supplemental irrigation is provided (41,53). Chemical methods of weed control are advisable since cultivation may damage shallow roots in heavier soils (12). Some yield increases have been observed following the application of moderate amounts of nitrogen fertilizer. Beyond some initial training to produce well-formed trees, pruning is necessary only to remove broken or dead limbs (18). Carob wood is susceptible to decay organisms and all branches to be removed should be pruned when less than 2-3 in. in diameter, leaving no stubs, in order to permit adequate callus formation (10).

Vertebrate herbivores such as deer, rats, gophers, squirrels, rabbits and livestock are serious pests of carob in some situations and can completely destroy new, unprotected plantings (11,18,62). The only major insect pest of carob in the Mediterranean is the carob moth (Ectomyelois ceratoniae Zell.) that enters through cracks that develop

as pods of some varieties ripen (18). Previous field infestation by this moth also facilitates later attack by other important pests during storage of dried pods (20). Carob has no major insect pests to date in California, although in some areas trees may be attacked by red scale and immature pods infested by the orange tortrix moth or almond borer (11,62). Fumigation or freezing harvested pods stops the spread of such pests in storage (62).

Carob Varieties

Over fifty cultivars of carob have been described, including traditional varieties from the Mediterranean and new selections from California (6,7,13,52,62). Cultivars exhibit a wide range of phenotypic characteristics, such as chemical composition, precocity, pod abscission, pollen viability, temperature and rainfall requirements, and yield (11, 18,62). 'Tylliria' is the principal variety grown for export on Cyprus. Other Mediterranean varieties include 'Amele', 'Casuda', 'Sfax', and 'Aaronsohn'.

Based on long-term evaluation of variety trials, several cultivars have been recommended for planting in southern California and surrounding areas (Table 1) (62). Along the coast to four miles inland, fog that often lingers during the pod ripening period may cause some high sugar varieties to ferment and become infested with insects before maturity. The intermediate zone, 4-10 miles inland, is said to be the best climate for carob culture. In warm desert areas, many varieties grow vigorously, come into bearing at an early age, and produce abundant crops when well irrigated. However, total sugar content of pods of most varieties grown in the desert have been observed by at least one author to be lower than when grown closer to the coast (62).

TABLE 1. RECOMMENDED VARIETIES FOR SOUTHERN CALIFORNIA CLIMATE ZONES

Variety	Total Sugars (Av. % by wt.)	Coastal (Zone 24)*	Intermediate (Zone 23)	Inland (Zones 19-22)	Desert (Zone 13)
'Aaronsohn'	-			X	
'Amele'	53.8			X	X
'Badan'	-	X			
'Bolser'	44.0			X	
'Casuda'	48.4		X	X	X
'Clifford'	52.9		X		
'Omikron'	48.5			X	
'Santa Fe'	47.5	X	X		
'Thomson'	-	X			
'Tylliria'	47.5		X	X	

Source: 62. *See New Sunset Western Garden Book, Lane Pub., Menlo Park, CA.

Carob Yields

Age of carob at which flowering and fruit set commence varies with

cultivar and environmental conditions, but ranges from five to eight years after budding (5,11,18,53). Since the crop is not thinned, trees normally have an alternate bearing habit, with a heavy crop followed by a light one the following year (11). In four average years, carob may yield one heavy, two medium and one light crop (11). Climatic factors such as a severe frost may destroy the entire crop for one, or even two years, and thus synchronize all the trees in an area to the same bearing cycle. Although disruptive economically, this could be beneficial for orchard sanitation by eliminating fruit on which pests survive from year to year (41).

Few accurate measurements of carob yields have been made and estimates vary widely, sometimes depending on the enthusiasm of the author toward promoting the crop. No individual records are maintained on the bulk of carob trees in the Mediterranean that are grafted wild seedlings not planted in orchards. Yield estimates in Spain may actually be inflated by local growers for tax purposes (23).

Average production over 22 years on unirrigated, scattered trees based on total acreages and exports on Cyprus was only 0.5-1.1 tons/ac., although very large individual trees yielded up to one ton each (18). Highest yields reported are 5.5 tons/ac. from well tended, irrigated orchards budded to good varieties (31). Yields from 15 year old trees at the Badan ranch averaged 0.4 tons/ac. in 1979 and 1980 (25). Very few actual measurements of yields from California plantings have been recorded; none were included in the otherwise meticulous records maintained at the Coit-Rittenhouse orchard (62,64). Potential yields in California have been projected as high as 4.4 tons/ac., extrapolated from yields of individual mature trees (11). (See Appendix)

Harvesting and Processing

Hand-harvesting is the most costly, labor-intensive and time consuming aspect of carob culture. With varieties that do not drop their pods when ripe, poles are used to knock individual bunches from the branches (62). Care must be taken not to damage flowers for next year's crop or bark (18).

Some form of mechanical harvesting is necessary to make production more economical, but development of specialized equipment may be required (22,62). Mechanical trunk shakers could be used to remove pods from varieties that do not shed them all naturally, perhaps coupled with the use of abscission provoking chemicals such as ethephon (22,27,49). However, trunk shaking or abscission chemicals may also remove the flowers for next year's crop. If the trees are grown on flat or gently rolling land that could be compacted with rollers, then pods could be gathered from the ground with specially modified mechanical sweepers similar to those now used to harvest walnuts and almonds in California. Self-propelled catching frames, as used to harvest some deciduous fruits, would not be feasible except for young trees due to the large size of mature carobs (27,28,49).

Carob grown on slopes too steep or rocky for tractor operation, as in

much of the Mediterranean, are sometimes harvested by spreading tarps beneath the trees to collect fallen pods, provided no rain occurs during harvest (11,23). Small, hand-held mechanical shakers and portable, sloping canvas frames could be used to harvest young trees in some situations (27). Special training of tree branches for mechanical harvesting may be necessary for success (28).

After ripe pods fall or are shaken from the trees, they are allowed to sun dry on the ground for up to two weeks (62). Transported to processing facilities, they are then fumigated and dried to a moisture content of 10% or less (18). Dried pods protected from insects and vermin can be stored for two or three years without appreciable loss of quality (62).

Commercial processing of carob involves first crushing the whole dry pods in a hammermill and then separating the kibble and seeds. Pods must be well dried before kibbling or otherwise will clog the mill (11). Kibble is sorted into size classes by rotating, differential sieves and seeds separated out by air grading (18). All carob exported from the Mediterranean is processed in centralized kibbling factories. A prototype farm-scale processing machine capable of handling 2-3 tons/day has been developed by the International Tree Crops Institute especially for the Badan ranch. It consists of a trailer-mounted hammermill, differential sieve sizes in a rotating drum, and centrifugal seed cleaner (25).

Alcohol Production

Experience has been gained in the use of carob as a feedstock for industrial alcohol production in Italy and other countries. Since the main fermentable constituent of the pericarp is sucrose, carob pods could perhaps be handled by the same extraction processes as for sugar beets or sugar cane. Sugars are first leached from kibble with hot water in continuous counter-current extraction vessels (58). Enzymes are also added to simultaneously hydrolyze carbohydrates and thus increase sugar yields. Sugar extraction in the steam jacketed, screw-conveyor type machines requires a total time of about one hour and is about 95-98% efficient (58,65). Processed solids (pomace) contain 50-75% moisture and are not bacteriologically stable. The pomace must be processed immediately or dehydrated for storage (65). Wet carob pomace could serve as a substrate for conversion by microorganisms to higher-protein feeds. Dried pomace could be fed directly, mixed with high protein supplements, or used as a fertilizer (37,48).

Fermentation of the aqueous carob extract begins by first diluting it with water to about 15% total sugars by weight. Adding some nutrients for yeast growth and adjusting the pH to 4-4.5 may be necessary. Dilute extract is then innoculated with a pure strain of Saccharomyces yeast and allowed to ferment to completion in 7-14 days (18). Important chemical by-products of fermentation include $(NH_4)_2SO_4$, cyanides, AcOH, butyric acid, Me_2O and butyrone (50).

Alcohol yields reported from experimental fermentation of carob extract

are above average. Yields of about three gallons of 10-12% alcohol by volume were produced from 100 lbs. of pods containing 40% total sugars by weight (50,55). A theoretical yield of 57 gal. of 95% by volume alcohol per ton of pods (40% total sugars by wt.) has been calculated (65).

Economics of Carob Culture

Practically all the carob kibble, powder and gum currently consumed by industry and individuals in the U.S. is imported from Mediterranean countries. Due to abundant supply and low production costs, prices of imported carob are low. In 1959, the price of kibble delivered dockside to California was $100/ton (62). Average export (FOB) prices from Cyprus in 1969 were $62.40/ton of kibble and $144-192/ton for seeds (18). Current export prices of kibble from the Mediterranean are $360-380/ton FOB or $700-800/ton delivered to west coast ports (25,64). The 1979 crop from the Badan ranch sold for $400/ton (whole pods, FOB) to a large food processor in Mexico City (25). High quality pods suitable for eating out of hand, usually only 2% of total production, can be sold in California at $0.80-1.00/lb. wholesale and carob powder currently retails for about $1.35/lb. (64).

As with accurate yield figures, detailed carob production costs in foreign countries are difficult to obtain since most growers farm small acreages and use family labor to tend and harvest the crop (18). Harvesting is the major cultural cost, accounting for nearly 30% of the average price paid to growers on Cyprus (18). When outside labor is employed, harvesting costs can exceed 75% of the grower's net income (23). Average production costs in Cyprus in 1968-69 were $12/ton and the average price paid to growers was $40.80/ton (18).

No records of production costs for any past or present carob plantings in North America are readily available for comparison. Higher domestic labor costs and land prices make the profitable commercial production of carob in the U.S. more tenuous than in other countries (24). Hypothetical per acre costs to develop a carob orchard in California today can be postulated based on average costs to develop walnut and pistachio orchards (54). Planting costs, based on 45 budded trees/ac. and including land preparation, surveying and staking, would be approximately $500/ac. Assuming only training, weed control and irrigation, annual cultural costs for each of the first three years would be about $75/ac. If no irrigation was necessary thereafter, annual cultural costs could decrease to about $50/ac. Use of tree shakers and hand gathering for harvest would cost approximately $150/ton. By planting on marginal land suitable for pistachios and purchased at $1500/ac., annual overhead costs would be about $300/ac., not including interest on accumulated investment. Assuming optimistic yield estimates of 5 lbs/tree in the fifth year, increasing to 100 lbs/tree in the twelfth year, and a market price for pods of $400/ton, gross income would not exceed production costs until at least ten years after planting. By comparison, walnuts require 7-12 years to reach this self-sustaining level at a current market price of $1000/ton in shell (25,54).

The foregoing economic analysis contains several broad assumptions and may not accurately reflect the true costs of establishing a commercial carob orchard in California. Time required to reach the break-even point would of course depend on the land price, interest rate on investment, capitol costs for specialized harvesting and processing equipment, labor rates and market prices for kibble, seeds and other by-products. These uncertainties are further exacerbated by the fact that no market has in the past or now exists for carob produced in the U.S. (25,64). The major U.S. industrial users of carob kibble and locust bean gum have fixed and dedicated sources of supply from the Mediterranean that provide abundant quantities at low prices. Even if carob could be economically produced in the U.S. at a price competitive with imported products, it is unclear how willing these large processors would be to buy domestically instead (25,64).

The profitable production of carob as a feedstock for fuel alcohol is even more uncertain, even if domestic markets could be established. Although the estimated yield of 57 gal/ton is high compared to other crops, production per acre would be relatively low based on average yields of about 2 tons/ac. (56,65). Assuming alcohol manufacturing costs of $0.60/gal., the price paid to growers could not exceed about $50/ton in order to remain competitive with other feedstock crops and keep the cost of fuel grade alcohol below $1.50/gal. (56). At such prices, it is obvious that carob pods could not be profitably produced solely for alcohol fermentation. Income would have to be maximized by selling higher quality pods for food use, seeds for gum, by-products of the pomace and stillage, and only culls for fermentation. As much on-farm processing of carob products as possible would increase potential returns to growers.

One possible alternative would be to use irrigation to maximize the vegetative growth of carobs planted in desert areas as field windbreaks to protect other crops. The annual biomass production of both pods and wood could then be harvested as feedstock for solid fuel boilers or other bioconversion plants (57). However, the overall energy efficiency of producing carob biomass as both wood and pods has yet to be calculated.

Production and marketing cooperatives could be very important for small-scale carob growers in the U.S. if local markets were established. Producer coops could help to finance the development of specialized mechanical harvesting equipment and on-farm processing plants, costs that would otherwise be prohibitive for most small growers. Almost the entire carob export crop from Cyprus is handled by marketing cooperatives that also own and operate centralized kibbling factories (2). Future growers may also be able to take advantage of producer coops that operate bioconversion plants to process similar feedstock crops such as sugar beets or cane.

Conclusion

Carob is well-suited to produce pods of high sugar content for food, fodder and fuel on land too dry, infertile or rocky to support most

other agricultural crops. It is an appropriate tree crop for a minimal energy input form of agriculture (26). Carob can potentially produce reasonable yields in some areas of the southwestern U.S. Its commercial feasibility in Mexico has already been demonstrated. Scionwood of superior cultivars is obtainable and many of the details of carob culture have been determined by earlier experimenters.

However, prospects in the near future for profitable, commercial carob production in the U.S. appear unfavorable. Lack of established markets for domestic kibble and seeds is the major reason for this pessimistic outlook, despite the fact that increasing demand in the U.S. for carob products is likely to continue. Furthermore, higher prices of labor and marginal land in the U.S. increase production and overhead costs, extending the time required until gross income exceeds these costs beyond that possible in other countries. Profitable production of carob pods solely as an alcohol feedstock appears to be even less feasible, although harvest of annual biomass from carobs incorporated into farmstead tree plantings may prove to be practical. In order to stimulate widespread grower interest in planting the tree, markets for domestic carob need to be expanded, not only of culls for fermentation, but also of higher quality pods for food processing, seeds for locust bean gum and the whole range of potential by-products such as feed, fertilizer and chemicals.

Applied research is also necessary to help reduce production costs and increase potential returns. Specific cost data for carob production in California needs to be compiled. Systems of mechanical harvesting, involving both varietal selection and specialized equipment, must be developed to reduce costly manual labor. Prototype on-farm processing machines for kibbling and grading the pods and seed need improvement. Experiments should be conducted on alcohol production to determine if the technologies developed for other feedstocks would also serve for carob. Finally, techniques for small-scale processing and creation of new commercial uses of other carob products such as pomace should be investigated.

APPENDIX

YIELD ESTIMATES OF CAROB

Location	Tons/Acre	Pounds/Tree	Source
Portugal	2.2	100-130 ("average") 300-400 ("good") 1600-1800 ("unusual")	60
Cyprus[a]	0.5-1.1 1.8[b]	27.8-61.1 100	18
Spain	0.9	330	23
Mediterranean	2.2	126 (4 year av.) 2000 ("unusual")	11
Mediterranean	0.1-1.1 0.4-2.7	4-55 (7-15 years) 22-132 (16-30 years)	53
Israel	5.5[c] 3.2[d]		31
Mexico[e]	0.4		25
California	0.1 0.9 1.75 4.40	5 (5th year) 50 (8th year) 100 (12th year) 250 (25th year)	11
California Desert	1.75	100 (12th year)	61

[a]Average of 22 years.
[b]Well-tended, good soils and rainfall.
[c]Irrigated orchard.
[d]Unirrigated orchard, 14 in. rainfall.
[e]Twenty year old trees

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THE CHINESE TALLOW TREE AS A CASH AND PETROLEUM-SUBSTITUTE CROP

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ABSTRACT

The Chinese tallow tree is an introduced semi-tropical euphorb now naturalized in the coastal lowlands from South Carolina to Texas and, under cultivation, capable of annual yields of over 4,000 lb/acre of vegetable tallow and oil. It grows in poorly-drained saline soils, is disease and insect resistant, and possesses considerable genetic variability. The tallow tree has a long history of culture, and its products are familiar to oil chemists; it is thus poised for development as a modern crop. The major technical barrier is the necessity for development of a system for mechanical harvest.

INTRODUCTION

There is a growing awareness that oil seed crops have considerable potential as a source of petroleum substitutes. They may be used directly as diesel fuel, are easily modified to substitute for other petroleum-based products, and are renewable. Seed fats undoubtedly will find increased utilization and markets as petroleum supplies dwindle.

We have been working toward the commercialization of a high-yielding perennial source of vegetable fat and oil. The system under development utilizes the Chinese tallow tree, Sapium sebiferum (L). Roxb. (Euphorbiaceae), an introduced species ~~that thrives in~~ the lowlands of the the Gulf Coast and lower Eastern seaboard, areas that are currently of marginal agricultural value. This report summarizes our understanding of the characteristics, the problems, and the potential of the Chinese tallow tree system.

BIOLOGICAL BACKGROUND

Tree Description

The Chinese tallow tree, sometimes called the Vegetable-tallow tree, is a subtropical species of the Euphorbiaceae, a native of China and now apparently found throughout the warmer parts of Asia. It is a small (30 to 40 ft), short-lived (40 to 50 years), deciduous tree resembling an aspen or poplar in overall appearance but with an asymmetrical, often gnarled bole. Leaves are 1-1/4" to 3-1/2" long, rhombic-ovate or orbicular-ovate, abruptly accuminate with smooth margins and have prominent glands at the leaf base. Leaves in the fall often exhibit brillant coloration which occurs even in the deep South and, in the various strains, ranges from yellow to purple-red. Flowering occurs in late spring and often produces spectacularly large terminal racemes of yellow flowers. Female flowers are at the base of the raceme, the males are clustered in the upper part of the inflorescence. After pollen maturation the major portion of the raceme, bearing the showy male flowers, separates at a well-defined abcission zone. Fruits develop in clusters (Figure 1) of 3- or 4-celled capsules which dry and split in the fall to expose single globose white seeds that are approximately the size of a pea. Seeds are often produced in such enormous quantities that a leafless tree in the fall, seen in reflected sunlight, resembles a huge cotton plant (Figure 2).

The seed, which is of primary interest here, is a biological curiosity. The white aril-like mass covering the seed, a white and greasy substance, is the so-called vegetable tallow and is composed of triglycerides containing primarily saturated fatty acids. The seed kernel contains a liquid oil known in commerce as stillingia oil, composed of triglycerides containing unsaturated fatty acids.

History of Introduction and Distribution

The tallow tree is found wild and is a semi-cultivated ornamental tree through most of the coastal region from southern North Carolina to south Texas and occasionally in California. It was introduced at several times and places. In South Carolina it was taken into the Charleston area during the very late 1700's by Francois Michaux the French botanist (Hunt, 1947). In the period from 1910 to 1920 the U.S.D.A. Bureau of Plant Industry cooperated with several nurseymen, notably in Houston, Texas and Jacksonville, Florida, in an attempt to establish commercial plantings of tallow trees for local soap industries. The tallow tree may also have been planted in California, but published records indicating the success or failure of such plantations have not been found.

The plantings at Jacksonville and Houston were unsuccessful. Although annual yields of 10,000 lbs/acre were reported (Bolley & McCormack, 1958; Potts, 1946), the overall program failed because hand harvesting was not economically feasible (Jamieson & McKinney, 1938; John Teas -- personal communication). The tree has spread widely from its original introduction points because of its extensive use as a fastgrowing, colorful ornamental and as a source of nectar in agriculture and honey production. The edible tallow coat of the seeds also renders them

Figure 1. Newly opened pods and seeds of Chinese tallow tree

Figure 2. A mature seed-bearing Chinese tallow tree in late October.

attractive to birds and this has provided another means of seed dispersal.

Cultural Characteristics

The Chinese tallow tree possesses a number of characteristics which recommend it as a crop species. It grows very rapidly, coppices well, sprouts vigorously from roots, produces suckers in abundance, and produces impressive crops of seeds. Moreover, the tallow tree is tolerant to salinity and of water logged soils. A deeply-penetrating root system renders it relatively drought resistant.

The tallow tree apparently has no natural enemies. It is not browsed by cattle. After more than three years of extensive observation on numerous stands, no serious cases of attack by insects or fungal/bacterial pathogens have been found. The tallow covering of the seed is, however, degraded by saprophytic fungi, most notably a black mold of the form-genus Pullularia. At advanced stages the hyphae penetrate the kernel of the seed and kill the embryo.

The manner of seed-bearing is one which suggests adaptability to machine harvesting. Flowers form at the terminals after a spring flush of growth, fruits form and seeds set. Often a second flush of growth occurs from a point below the fruit cluster. In the fall, when ripening occurs, the capsules turn black, dry and fall off, exposing the white seeds which remain persistently attached to short pedicels or floral stalks. At any time during the ripening process, the seed clusters are susceptible to removal by hand or mechanical means. The traditional Chinese method involves removal of the capsules before opening by cutting the inflorescence axis with a hooked knife attached to a long pole. Capsules are then allowed to dry and open. Seeds are winnowed from the stalks and hulls (MacGowan, 1852; Lin, et al, 1958).

The interesting point is that in winter much of the second flush of growth, as well as the fruit-bearing stalks, die back. The new flush of growth occurs from a point very near that of the previous year. The tallow tree is not shade-tolerant and the major growth occurs in the periphery of the crown. The harvestable crop is thus borne largely in the periphery of the crown, where it is readily accessible, on shoots which are, in any case, lost through natural pruning or abscission.

Compared to many perennial crops, the tallow tree becomes productive relatively early. Sexual maturity is reported in 3 to 5-year old trees; we have observed occasional flowering in two-year planted stands. Although the tree is monoecious and over 80% of them in a three-year old plantation produced flowers, most were only male and seed set occurred in less than 1% of the trees. Hsu (1928) and Lin, et. al. (1958) indicate that useful seed yields may be obtained within five years and yields do not decline for 25 to 30 years.

Genetic Variability

The Chinese literature indicates extreme variability within the species (Lin, 1958; Shin, 1973). The tallow tree population in the Houston area also appears to reflect a high degree of genetic diversity.

Overall tree form on the same site ranges from a very low tree with forked and spreading branches to tall trees with single or branched boles. Leaves range from small, yellow-green and just over one inch long to dark green and nearly four inches long. Arrangement of fruit stalks varies considerably. At one extreme are plants with large numbers of thin, drooping or pendant flowering branches growing from a few large main branches. At the other extreme, seeds are borne in the terminals of highly branched stems. Fruit bearing branches range from very heavy and stiff with persistent seeds to delicate and fragile with easily lost seeds.

Two distinct flowering forms are found in the vicinity of Houston, Texas. One type produces only staminate racemes in the early spring which then wither and fall off. Subsequently, a second flush of 3-4 small branches occurs and an androgenous raceme which demonstrates protogyny (the female flowers are receptive to pollen before the male flowers are mature enough to shed pollen) develops at the end of each branch. The other flowering form produces only androgenous racemes that are protogynous. The number of female flowers per raceme varies but may be as high as 10 or 15.

There are two distinct configurations of axes bearing seeds. These are termed "eagle claw" and "grape" in the Chinese literature (Lin, et. al. 1958). The number of seeds on a tree ranges from no seeds (primarily young trees), a few single-pod axes containing two or three seeds, to large clusters produced in numbers sufficient to deform or break limbs. Seeds also vary in size, ranging from 4360 to 2080 seeds per pound (9600 to 4580 per kilogram).* Seed pods on some trees open as early as mid-September while others characteristically remain closed and green until mid-November. Many trees continue throughout the years to produce large quantities of seeds per raceme. Numerous capsules are formed, each with 3 seeds. Only 3-4 capsules per raceme may form, with only one or two mature seeds each. Whether this is the result of lack of pollination or early abortion due to inbreeding is not known. Trees in the Charleston, South Carolina area tend to produce only 2 or 3 capsules per raceme, considerably fewer than those in the Houston, Texas area (3-8).

Isozyme electrophoresis is being used to characterize trees from various geographical localities in the United States. Seed isozyme banding patterns demonstrate Mendelian segregation and are thought to be genetically controlled. If this is true, preliminary results indicate founder effect and genetic drift which has resulted from limited introductions from China. In spite of this, the United States genome consists of a surprising number of polymorphic loci. Thus far, ten enzyme systems encoding a minimum of 14 loci have been defined.

All observations suggest great genetic plasticity and considerable potential for selection of desirable characteristics in terms of productivity and adaptability to harvesting techniques.

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* Scheld unpublished - Based upon measurements of air dry seeds from ten random trees in the Houston area.

Ecology

Few ecological studies have been conducted on the Chinese tallow tree and much of what is known is anecdotal. The reason for this is that the Chinese tallow tree has been used primarily as an ornamental, and instances of its occurrence in natural system have been scattered. Nonetheless, a large stand has been growing and extending itself as a component of the native Texas coastal prairie for the past 35 years, this in spite of the fact that the tallow tree exhibits the general characteristics of a pioneer species and would not be expected to maintain itself as a climax forest. Mechanisms of competition can only be guessed. The sites involved are low and wet. Tallow trees are apparently salt tolerant, having been reported as common in salt marshes and along salt creek borders (Hunt, 1947). Root systems appear remarkably tolerant of anaerobic conditions and penetrate deeply in water saturated, dense clay soils. The leaves and sap contain strikingly high amounts of secondary phenolic metabolites.

One of the most striking observations of tallow tree stands is the absence of associated insect fauna; a lack of insect damage is very unusual, especially for a subtropical area. Since the introduction of the Chinese tallow tree is recent, the lack of herbivory could be due to the fact that development of an associated insect fauna takes time (Southwood, 1961). Alternatively, the lack of herbivores could be due to the presence of secondary chemical compounds which inhibit insect feeding as shown for oak by Feeny, (1968, 1970).

Cameron and LaPoint (1978) showed that secondary compounds (tannins) in Chinese tallow trees affect reducer (and probably herbivore) organisms. Tannins alter the structure of the aquatic fauna in ephemeral ponds in the tallow forest; reducer organisms (which feed on coarse particulate organic matter) are especially affected and consequently the rate of nutrient recycling in the tallow forest is slowed. Terrestrial reducer organisms (primarily isopods, Armadillidium vulgare) will not consume fallen tallow leaves until spring rains have leached the tannins. Hence, decomposition of tallow leaves and consequently nutrient recycling in this system is dependent upon leaching of tannins.

We may speculate that leaf tannins have a more general role in the ecology of the tallow forest.

Seed Properties

The triglycerides of the tallow covering of the seed are composed of saturated or mono-unsaturated fatty acids enriched in palmitate, stearate and oleate (Table 1). The properties are such that the tallow is potentially a substitute for cocoabutter as a confectioners' fat (Hilditch and Priestman, 1930; D. A. Leo, personal communication).

The oil of the seed is highly unsaturated and contains predominantly triglycerides of oleic, linoleic and linolenic acids (Table 1). It compares favorably with other commonly used drying oils (Bolley and McCormack, 1950). The fatty acid composition of the oil is of particular interest because it contains two unusual short-chain fatty acids joined by an estolide linkage (Sprecher, et. al., 1965; Christie, 1969).

The oil is composed of normal triglycerides and some testraester triglycerides which contain the estolide linkage.

TABLE 1. Compositional data from the available literature reporting analyses of tallow seed components. Ranges are derived from the highest and lowest values reported in the literature cited. Houston tree analyses were performed by a commercial oil seed laboratory. The report of Christie is the only thorough analysis of the unusual fraction of the oil.

Fatty Acid		SEED COAT (TALLOW) Range Reported*	Houston Trees Tree 1	Tree 2	SEED OIL Range Reported*	Houston Trees Tree 1	Tree 2	Christie (1969) Report
C-12:0	Lauric	0.3 - 2.4%	0.22			4.46		
C-14:0	Myristic	0.5 - 5.8%	0.12	—		—	5.00	
C-16:0	Palmitic	57.6 - 72.1%	65.24	67.50	4.4 - 6.4%	5.57	6.45	5.6%
C-18:0	Stearic	1.2 - 6.4%	0.95	1.36	1.0 - 2.64%	2.19	1.87	1.7%
C-18:1	Oleic	20.4 - 34.5%	30.43	28.58	7.7 - 11.8%	13.64	10.92	12.7%
C-18:2	Linoleic		2.25	2.54	25.8 - 56.3%	33.37	29.26	23.4%
C-18:3	Linolenic		0.76		24.6 - 42.3%	40.74	46.47	48.9%
Trace Components		2-5%			0.1 - 10.0%			
Estolide-linked Group					8.7%			7.7%

* These values are composite from several sources (Hilditch and Williams, 1964; Hilditch and Priestman, 1930; Jamieson and McKinney, 1938; Kahn, Kahn and Malik, 1973; Maier and Holman, 1964; Narang and Sadgopal, 1957).

Total fat content of seeds is highly variable. Bolley and McCormack (1950) report for a composite sample 23% tallow, 17% oil, 11% protein, and 41% shell with the remainder in fiber, ash, etc. Lin (1958) reports tallow contents ranging from 11% to 32% and oil contents ranging from 11% to 24% based upon total seed weight. Our preliminary analyses suggest that the tallow is highly variable ranging from 15 to 30% of total seed weight while oil content based upon tallow-free seed weight is relatively constant.

None of the reported analyses identify seed sources in detail, but obviously the sources were diverse. It is apparent from the reports and from our own samples that relative concentration of fatty acid components exhibits a considerable variability among strains. This points to a considerable potential for genetic maniupulation of fat yield and quality.

The amino acid composition of the defatted, dehulled meal as determined by microbiological methods has been reported by Holland and Meinke (1948) who suggested that the meal should be adequate for use as livestock feed supplement or in baking flours. More recent amino acid analyses have not been reported in the literature nor have feeding trials of the meal been published.

ECONOMIC VIABILITY

The development of a new crop is an uncertain venture at best. There is added risk when the crop plant is a tree, and thus the undertaking must have some very strong drivers. The following factors were considered in the decision to pursue development of the Chinese tallow tree:

Hydrocarbon Nature of Seed Fats and Oils

Pryde (1979) presents a compelling argument for the increased industrial use of vegetable fats and oils:

> "There does not appear to be any reason that more vegetable oils could not be made available for greater use in industrial products. Land is available (1, 2). Crop production costs are relatively small and less than subsequent processing costs (1). Prices for fats and oils have not increased at the same rate as those for petrochemicals (3).
>
> It is time to evaluate the relationship of fats and oils as renewable resources relative to petrochemicals as non-renewable resources, and to determine if fats and oils are committed only to their historical uses, or additionally, to new value-added products needed by our technological society. Such evaluation is necessary in view of our increasing dependence upon imported oil and the resulting trade deficits."

Princen (1979) estimates that only about 60 million acres (at an assumed annual yield of 10 barrels per acre) would be needed to produce a replacement for the approximate eight percent of our petroleum usage which goes into chemical production. Impending oil shortages/price increases ensure that this will happen. But the size of the market should increase beyond synthetic organics.

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1. Pryde, E. H., in "Crop Resources," edited by D. S. Seigler, Academic Press, New York, 1977, pp 25-45.

2. Princen, L. H., J. Coatings. Technol. 49(635): 88 (1977)

3. Pryde, E. H., D. D. Hacklander and H. O. Doty. Abstracts of papers, 173rd National Meeting, American Chemical Society, March 20-25, 1977, New Orleans, Louisiana. Abstract No. 79, Division of Agriculture and Food Chemistry.

The use of vegetable oils as diesel fuel is receiving increasing attention. Tests began before World War II (Walton, 1938; Aggarwal, et. al., 1952) and have continued until the present (Engelman, et. al., 1978; Sandvik, 1979; Warmington, 1979; Zimmerman, 1980, Bruwer, et. al.,1980). With few exceptions (castor oil,for example, produced smoke and carbon), every liquid oil tested performed adequately with the provision that some pre-heating is necessary outside the tropics. Given the apparent utility of vegetable oils as diesel fuel substitutes, it is expected that farmers will increasingly look to such sources as dependable local fuel supplies. Moreover, the relatively low level of technology required for production and the apparently favorable energy balance would appear to place vegetable oils as important back-up liquid fuel supplies for on-the-road transporatation in the event of a petroleum short-fall. Of additional interest is a recent report (Weisz, et. al., 1979) in which vegetable oils were converted to gasoline by passage across a zeolite catalyst at high temperature and pressure.

Unique Economics of Chinese Tallow Tree Seed Products.

A significant obstacle to the development of alternative energy sources is a hesitancy on the part of would-be investors because of near-term uncertainty of markets and of marginal current value regardless of expected increases in future value. The Chinese tallow tree enjoys a unique advantage in this respect. It is now potentially a valuable cash crop, regardless of its future utility as a source of chemicals/ fuel.

The reason for the tallow tree's high value lies in the dual nature of the seed products. The vegetable tallow coating(the outside of the seed) and the seed kernel containing the liquid stillingi oil are separated by a hard, impermeable shell. The two components may be recovered separately by a procedure (C. R. Engler, unpublished report, Texas A & M Food Protein Research and Development Center) in which the intact seed is first solvent extracted to remove the tallow and then the shell is cracked to expose the oily endosperm for a second extraction. The vegetable tallow is, as previously noted, a potential cocoabutter substitute. The current market price for cocoabutter, an imported item, is in excess of $2.00 per pound and in a preliminary probe of possible markets, buyers have estimated the potential market price of Chinese vegetable tallow to be possibly only 10% below that of cocoabutter. Further, the seed contains approximately 11% protein which adds to the overall market value.

One oil seed buyer undertook a preliminary analysis of the profit potential of the Chinese tallow tree utilizing the most conservative values from their own experience combined with published yield values. Factors, such as cultivation and harvesting costs, which are as yet unknown, but which are expected to be relatively low in comparison to conventional corps, were taken into account. Assumed was an annual yield of 10,000 lbs/acre as estimated by Potts (1946) and Bolley & McCormack (1950), with conversion of the seed to:

1,485 lb. of tallow, valued by the processor midway between palm oil and palm oil stearine at $.70/lb;

1,537 lb. of oil, valued by the processor midway between linseed oil and tung oil at $.42/lb;

2,578 lb. of meal, valued as linseed meal at $175.00/ton;

3,900 lb. of shells, valued lower than cottonseed hulls at $40.00/ton;

to yield a total cash value of $1,988.12 per acre. Costs to process were:

Direct conversion, estimated at twice soybean costs	$ 85.00
Profits, overhead, etc., of 25%	497.00
Transportation, storage, etc., of 5% (4 months at 1% + 1% transportation costs)	99.40
TOTAL PROCESSING COSTS PER ACRE YIELD	$681.40

Costs of land, stand establishment and cultivation were estimated on the basis of known costs of converting and planting mesquite savannah grazing land in the southern Texas Gulf Coast:

Land rental with a starting lease cost per acre	$ 10.00
Bulldozing	20.00
Discing (4 passes at an average cost of $15.00/pass)	60.00
Subsoiling and/or leveling	10.00
Herbicide or cultivation	15.00
Seeds (at this point it is assumed that direct seeding is the only economically viable method of stand establishment and that reasonably high-yielding stands can be established by direct seeding methods)	20.00
Planting with a conventional multi-row corn or cotton planter	25.00
Fertilizer	40.00
TOTAL ESTABLISHMENT COST	$200.00
Carried for 7 years at 15% interest, this is	$532.00

There would also be annual costs of stand maintenance and land rental which might total $100.00. Carried at 15% interest for 6 years, this would total $1,104.00. The foregoing assumed a "worst case: in which payback does not begin until full production is reached in 7 years. In fact, trees begin producing by at least 4 years, and thus full payback may be expected at or before 7 years. Production beyond that point becomes highly profitable. In summary, costs and revenues per year (in 1979 dollars) after 7 years of operation were:

Value of products	$1,988.12
Less costs and profits to processor	-681.40
Less costs of stand maintenance and harvesting, estimated at worst case	-200.00
NET REVENUE TO FARMER	$1,106.72/acre/year

A Texas cotton farmer does well to receive a net revenue of $300.00/acre annually. Thus, in the first instance, the Chinese tallow tree may be viewed as a cash crop which has a sufficiently high value to encourage large-scale planting. Once planted, it constitutes a more or less permanent hydrocarbon resource reserve. Second, because of the high value of the tallow, it subsidizes in effect the production of the entirely separate seed kernel oil, which becomes an inexpensive, combustible, liquid fuel/diesel oil substitute or raw material for chemical synthesis.

TECHNICAL VIABILITY

In many respects, the Chinese tallow tree is relatively far advanced toward development into a modern crop.

1. The tree is not a wild plant being newly domesticated; it has been cultivated for centuries (MacGowan, 1952; Shi, ca 1977) under a traditional agricultural system. Thus, much is known about fundamental aspects of culture and current growing stock is the result of a considerable empirical selection program.

2. The tree is already well-adapted and growing vigorously throughout the coastal, southern U. S.; the aspects of its culture are well known in the U.S. because of its extensive use as an ornamental plant.

3. From both the Chinese literature (Shin, 1973, Lin et al 1958) and reports of early efforts in the U.S. (Bolley & McCormack, 1950) it is well established that the tree is capable of producing high yields of seeds under a labor-intensive system of culture.

4. The growth characteristics of the tree and nature of the traditional Chinese methods of harvesting suggest that

the tree will be adaptable to mechanized harvesting techniques.

5. The possible uses and general chemistry of tallow tree seed products are well established in the literature (MacGowan,1858; Hsu, 1928, Lin, et. al., 1958; Shi, ca 1977; and the references listed in Table 1).

6. Preliminary tests of seed processing suggest that currently available equipment may be adapted for use in processing of commercial quantities of seeds (C. R. Engler, 1980, unpublished report, Texas A & M Food Protein Research and Development Center).

7. Preliminary tests of stillingia oil in test bed diesel engines indicate that the oil is an adequate diesel fuel. The Chinese have apparently also tested it and found it acceptable (Shin, 1973).

There are, however, several uncertainties upon which the feasibility and/or time frame for development of the Chinese tallow tree as a crop rest:

1. Markets for tallow tree products are not developed and the seed processing technology which forms the first step in the marketing process is yet to be fully defined. Establishment of markets is absolutely essential if potential investors are to risk the somewhat larger initial investment and longer payback of the tallow tree compared to conventional annual crops.

2. A full understanding of feasibility and the ultimate potential of the plant depends upon a more complete understanding of the biology of the plant: its genetics and reproductive strategies, the methods by which desirable clones may be propagated on a massive scale, and the full extent of the potential environmental impact of establishment of extensive plantations in areas which formerly have supported mixtures of diverse tree species or only low shrubs and grass.

3. The use of mechanized harvest methods is absolutely essential for successful use in the United States. The growth characteristics of the plant indicate adaptability to mechanical methods, but at this point, only a few comparisons are available with somewhat similar crops already under machine harvesting regimes. Moreover, the interaction between the machine, the crop configuration, and the complex of necessary agronomic practices can be visualized vaguely, but requires concrete data and experience.

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A PLANT BREEDER LOOKS AT SOME AMERICAN TREE CROPS: _MORUS_, _GLEDITSIA_, AND _DIOSPYROS_

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Tree fruits and nuts have come from various continents and climates. We can utilize some of these renewable plant products for animal feed, human food, or fuels for our machines. I will center my discussion on three genera, _Morus_ (the mulberries), _Gleditsia_ (the honeylocusts), and _Diospyros_ (the persimmons). Trees of these genera include several that are hardy; at least medium long-lived; and adapted to selection and breeding, asexual propagation, and relatively quick production of fruit crops potentially useful for food, feed, or alcohol distillation.

Mulberries

Different species of mulberries grow north from the tropics into Canada and Northeast Asia. The most abundant cultivated and naturalized species in the northern areas is _Morus alba_, the silkworm mulberry of China. It has hybridized in this country with _M. rubra_, which is less useful for silkworm feeding, but generally produces a better flavored fruit (and better timber, given time). The third important edible species, _M. nigra_, is a Persian native, hardy only in the southern area of the U.S. Because of its unusually high ploidy, it appears unlikely to cross with either _M. alba_ or _M. rubra_, both diploids.

Like the related figs, mulberries have been most used as staple foods in climates with generally dry seasons and sunny harvest times, such as in the Near and Middle East. They may be grown in more humid regions, but with greater fruit losses when preserved without costly dehydration processes. We may still use them, in season, for poultry and swine feed. With proper collection procedures, we could use them for alcohol feedstocks.

Commonly grown mulberry species share another characteristic of the fig: they mature their fruits whether or not they are pollinated. Both _M. alba_ and _M. rubra_ normally have a range of sexual expression, but pistillate and largely pistillate clones may be grown without staminate clones nearby; the same is true with _M. nigra_. _M. alba_, and at least some of its hybrids with _M. rubra_, propagate readily from hardwood cuttings. Hybrids can be grafted on stocks of either parental species. I have had the most experience with the hybrid "Illinois Everbearing," hardy to U.S.D.A. Plant Hardiness Zone 5.

Some older cultivars of apparently hybrid origin are less hardy, among them "Hicks" and "Stubbs."

The oldest mulberry hybrids may date back nearly to the settlement of Jamestown, Virginia, in the early 1600's. Sericulture was tried without success in this early Virginia colony; consequently, M. alba was introduced to America. While silk culture never really "took" under American conditions, the Old World mulberry, like so many later introductions, became naturalized. It made natural hybrids with the native M. rubra (whose range is from the Florida Everglades north into New England and Minnesota); some of these hybrids proved to be superior in vigor, disease resistance, and fruitfulness. Some were propagated as fruiting cultivars, but their hybridity generally was unrecognized until recently. Only in 1945 did A. F. Yeager and his associates at the University of New Hampshire produce controlled hybrids of M. rubra and M. alba.

The hybrid fruits generally have a more sprightly flavor than the fruits of M. alba, which are low in acid when ripe. Some of the introduced cultivars, including the three named above, have an extended ripening period, hence the "everbearing" designation. This would probably be a disadvantage in commercial harvesting, either for drying or for alcohol production, but provides a long season "cafeteria" for birds, including poultry.

Mulberries offer promise as tree crops for mixed wildlife and livestock plantings over the wide area of the U.S. where M. alba is already naturalized. They will need selection and/or breeding to become a future alcohol sources.

Honeylocusts

Gleditsia triacanthos, like the mulberries, varies greatly in sexual expression. In recent years, honeylocust have been seen mostly as an ornamental shade tree, for which the thornless "male" cultivars have been budded. Few of these except the first one patented, "Moraine," are 100% staminate under all situations.

Most cultivars can be maintained as thornless, even those not genetically thornless. Most honeylocusts produce fewer thorns in the upper, flower-bearing branches as they attain maturity, until,with increasing age, the flowering part has no thorns at all. Budding or grafting from the mature part of a tree will yield a thornless cultivar. Of course, thorns are a hazard to animals browsing on honeylocust pods. We have seed sources for rootstock production which, when grown far from genetically thornless trees, will produce seedlings that are well over 90% thornless. These seed source trees tend to be mainly of northern and western provenance. Unfortunately, trees from regions with low genetic thorniness tend to have pods which are much lighter in weight and lower in sugar than some honeylocusts from the Southeast, where "Millwood," "Calhoun," and other particularly sugary-podded trees originally grew. It would be

possible, by sustained breeding effort, to combine the southern race with the northern race to obtain fully thronless tree worth growing for pods, and also adapted farther north and west than "Millwood."

I participated in the original selection and did the very first grafting from "Calhoun," found near Gadsden, Alabama; within a few years, I observed the original "Millwood," near Lake Junaluska, North Carolina. "Millwood" was not entirely thornless on the original tree, while the larger fruited "Calhoun" tree had about average thorniness for an Alabama seedling. Both have been vegetatively propagated from thornless wood and have continued to be phenotypically thornless.

Some preliminary breeding has been done with "Millwood," which is currently the most promising honeylocust cultivar for pod production. In the late 1930's, I saved seeds from it at Norris, Tennessee, while with the Tennesses Valley Authority; apparently, the seedlings were later discarded. More recently, at Urbana, Ullinois, where two grafted "Millwood" trees were growing, I grew seedlings and selected an entirely thornless, vigorously growing, purely staminate seedling now named "Urbana." The nearest pollen sources was "Moraine." "Urbana" is more erect and has faster growth than "Moraine"; it was selected as an ornamental shade tree cultivar, but its greatest value in the long run may be as a parent in breeding better fruiting cultivars.

Others in Illinois have raised more seedlings of "Millwood," notably Ralph Kreider of Hammond, who has many trees, some approaching "Millwood" in pod size and quality (their likely staminate parents were Central Illinois native trees). The next breeding step could be controlled crossing of some of the Mr. Kreider's best trees with "Urbana." Two other thornless, hardy, vigorous, mainly staminate honeylocust cultivars with breeding values are "Green Glory" (Plant Patent No. 2786) selected by Ralph Synnestvedt, a nurseryman in Glenview, Illinois, and "Beatrice," selected as a seedling in the Nebraska town of that name. Neither is 100% staminate.

Altogether, there are about twelve species of Gleditsia. Gleditsia aquatica, native to swampy sites from South Carolina to Florida and Texas, has produced natural hybrids with G. triacanthos. Frank S. Santamour, Jr., of the U.S. National Arboretum, Washington, D.C., is hybridizing G. triacanthos with some of the foreign species, which may add resistance to some of the serious insect and disease problems of honeylocust. Dr. Santamour is looking at honeylocust both as an ornamental tree and as a pod producer.

Honeylocust is not the perfect shade tree that its promoters, beginning around thirty years ago, have touted it to be. In much of the East, city plantings are now disfigured each summer by foliage feeding of the mimosa webworm, unless chemical spray programs are employed. There are other insects and mites that distort the

foliage, and a variety of fungal and bacterial diseases that usually make the honeylocust a short-lived tree, compared to some oaks and certain ornamentals. As an economic tree, its potential is probably greater. Though primarily a tree of fertile flood plains, it will grow on poorer and drier sites. On the none-too-fertile soil of the Auburn University Agricultural Experiment Station, Auburn, Alabama, my former classmate J. C. Moore put a small plot of grafted "Millwood" and "Calhoun" honeylocusts; these trees, particularly the "Millwood," outperformed (non-hybrid) corn in yield for livestock nutrition.

At Urbana, Illinois, the two "Millwood" trees, now over forty years old, and other honeylocusts have not been so productive as Moore's, yet they are on soil more productive for corn than was the Auburn soil. The Illinois trees have been grown without much added NPK, under a grass sod, and one of the "Millwood" trees has been crowded by other tree seedlings which have competed greatly with it. The Auburn trees were grown in lespedeza.

Persimmons

From near-subtropical southern Florida, north to New England, west to Iowa and Kansas, south through much of Texas; in wood borders, fields, and roadsides, in a great range of soil conditions from rich to marginal, the deep-rooted, drought-resistant native persimmon bears its annual crops of sugary fruits. Regarded by many farmers and ranchers as a weed tree, relished by others as a gourmet food, it has many detractors, many enthusiasts. Today, there are breeders of *Diospyros virginiana*.

The Oriental peoples for over 1000 years have cherished two other *Diospyros* species of temperature regions: *D. lotus* and the larger-fruited, more highly selected *D. kaki*. The latter now has literally thousands of cultivars, some greatly refined from the ancestral wild types, grafted by farmers and by commercial orchardists. It is a staple fruit of China, Korea, and Japan. By contract, the smaller American persimmon has been grafted in the U.S. for only a little more than 100 years. Therefore, the Oriental *D. kaki* is much more highly developed as a fruit crop, and it has had more scientific breeding recently.

Both of these species share some characteristics. The Oriental persimmon is more highly developed in the following: fruit size; self-pollination (some cultivars); parthenocarpic tendency (holding seedless fruits); cultivars non-astringent before softening; cultivars adapted to commercial shipment. The American persimmon generally excels in these areas: tree hardiness (northern race); adaptation to varied soils; sugar content of fruit; later flowering (escape from late frosts); yields of fruit; early fruit maturity (certain cultivars).

Selected hybrids between the Oriental and American species would have obvious advantages, but attempts to hybridize D. virginiana with D. kaki have been made by American and Japanese breeders, without success. A Soviet breeding program at the State Nikita Botanical Gardens, Yalta, Crimea, U.S.S.R., reports fruitful hybrids; no scions have been sent to scientists outside the U.S.S.R. for corroboration, however. (These breeders have additionally claimed hybrids between dipoloid D. lotus, 2n = 30, and hexaploid D. kaki 2n = 90, and hexaploid or tetraploid D. virginiana, 2n = 90 or 2n = 60. American experiments indicate a lack of breeding compatibility between species and races of persimmon with differing chromosome numbers, though they inter-graft successfully.) Both the late Eugene Griffith and I have tried crosses between D. kaki and the hexaploid race of D. virginiana. We obtained a small number of seedlings, but in all cases these inherited only the maternal parent's characters, and thus must be attributed to apomictic embryo development rather than true interspecific hybridization. Future hybridization awaits perfection of such techniques as excised embryo culture and in vitro fusion of gametes from the two parents, techniques not yet well worked out for woody plant species.

Meanwhile, selection within D. virginiana has resulted in numerous cultivars with horticultural promise for different areas of the U.S. Some of these are potentially useful as sources of alcohol. The longest and most succcessful selection for fruit quality has been within the northern and western race (hexaploid) from Illinois, Indiana, and Missouri original sources, and cultivars from these original sources furnish most of the parents in current breedings. The 90-chromosome cultivars of the "Early Golden" family show the widest climatic adaptation of American persimmons tested so far. Oldest of these is "Early Golden," selected at Alton, Illinois, before 1890 by E. A. Riehl. From it were raised such seedlings as the generally larger "Killen" and the better flavored, earlier maturing "Garretson." In turn, a seedling of "Killen" from the University of Illinois orchard at Urbana, Illinois, produced "John Rick", now the most favored cultivar among persimmon testers in the middle latitudes (Illinois to Pennsylvania) and successful south to Hattiesburg, Mississippi. The "Meader" cultivar, raised at Rochester, New Hampshire, as a seedling of "Garretson" excels the others in proven hardiness, but in Illinois ranks below "John Rick" in fruit flavor, size, and fresh appearance. In isolation it has the strongest parthenocarpic tendency, but it tends to have more seeds than the others when pollinated.

The finest flavored persimmon under Illinois and Indiana conditions is "Morris Burton" from near Mitchell, Indiana (not in the "Early Golden" family). Also not of the "Early Golden" lineage is the fine flavored and particularly early maturing "Wabash" from Lawrence County, Illinois; "Wabash" is smaller fruited than those previously mentioned, but it has a high degree of parthenocarpic fruit development where compatible pollination is absent. Other 90-chromosome persimmons being tested in breeding for their fruit size

and productivity, though distinctly inferior in fruit quality, include "Golden Supreme" from Illinois and "Marion" (often mislabeled "Miller") from Missouri.

Members of the "Early Golden" family with some production of staminate flowers on predominantly pistillate cultivars include "Early Golden," "Garretson," and "Killen"; in all likelihood, "Meader" also, which recently has had seeds in some fruits on its original isolated tree. Such cultivars are self-compatible when staminate flowers are produced, and offer the possibility of inbreeding to intensify their good characters. These cultivars may also be used as staminate parents in outbreeding, with the obvious advantage they offer over uncontrolled open pollination. Strictly staminate cultivars in the "Early Golden" family include "George," a vigorous tree which produces abundant flowers over a long season.

Persimmons of the less hardy 60-chromosome race that have a tendency toward parthenocarpy include "Penland" from Northern Carolina, which is early maturing, and probably "Gehron," a late maturing selection from Louisiana. "Penland" will develop seeds with compatible pollination. An apparently anomalous cultivar is "Knowles," whose original tree in Gibson County Indiana, now dead, was perhaps the largest and most productive American persimmon, bearing as much as a ton of soft, 99% seedless fruits. It died without suckering after a brushpile was burned against its great trunk, which was measured at 14 feet, 2 inches in circumference. Grafts have survived elsewhere, including one at Urbana, Illinois, where it is so late-ripening and small-fruited that it is of no interest as a fruit producer here. Perhaps "Knowles" at or south of its original site would have more value.

I have furnished propagation materials for many of the cultivars mentioned above to both professional and amateur propagators, and will continue to suggest reliable sources. My leaflet on chip-budding, a widely used progagation method, is available from the University of Illinois Horticulture Department. And I am editing the book Persimmons for Everyone, to be published soon by the Northern American Fruit Explorers, P.O. Box 711, St. Louis, MO 63188.

Session II

Systems Aspects of Tree Crops
Chairman — Carl Strojan
Environmental and Social Impacts Group, SERI

"I see a million hills green with crop-yielding trees and a million neat farm homes snuggled in the hills. These beautiful tree farms hold the hills from Boston to Austin, from Atlanta to Des Moines, Spokane and Edmonton. The hills of my vision have farming that fits them and replaces the poor pasture, the gullies, and the abandoned lands that characterize today such a large and increasing part of these hills.

"First of all a *new point of view* is needed, namely, that *farming should fit the land.* The presence on the land of the landowner is also needed. This is not a job for tenants. Let the tenant go down to the level land which carelessness cannot ruin so quickly. Not his the beautiful home in the beautiful hills."

J. Russell Smith

PRELIMINARY ANALYSIS OF THE POTENTIAL FOR ETHANOL PRODUCTION FROM HONEYLOCUST PODS

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Introduction

This paper reviews research at the Center for the Biology of Natural Systems on the potential for alcohol fuel production from biomass. Tree crops are one of the many possible sources of biomass for fuel and feed production under consideration. Because of their relatively low yield of ethanol per acre, tree crops such as the honeylocust are not likely to be used for fuel and feed production on high quality land currently under intensive cultivation. Acreage now used for row crops can be made more productive if appropriate shifts are made towards sugar crops which yield large quantities of both ethanol and livestock feed. Honeylocusts are an attractive biomass crop because they can be grown on marginal land, yield an annual crop of pods with a high sugar content, and improve resistance to soil erosion. In addition, commercially proven technology is available for conversion of honeylocust pods to ethanol and livestock feed.

The Potential for Alcohol Fuel Production from Biomass

Research at the Center for the Biology of Natural Systems (CBNS) indicates that as much as 35 billion gallons of ethanol could be produced annually from agricultural crops in the U.S. with no reduction in the availability of livestock feed. If one adds to this figure the amount of ethanol and butanediol (also a high quality liquid fuel, derived from fermentation of the pentose sugars in hemicellulose) available from the lignocellulosic residues in agriculture, forestry, and municipal solid waste, plus the ethanol which could come from tree crops planted on cropland pasture (discussed below), then the potential liquid fuel production from biomass exceeds the current demand for gasoline of about 100 billion gallons per year (Commoner, 1980 and Carlson et al., 1980).

The cornerstone of the CBNS model of ethanol production from agricultural crops is the flexibility of the U.S. agricultural system to respond to a new goal: production of food and fuel. Clearly, if ethanol production is imposed on the present agricultural system--

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meaning a reliance on corn as the major feedstock--then the overall potential for liquid fuel production will be severely constrained because the availability of metabolizable energy in livestock feed will decrease, thereby leading to an increase in the price of livestock.

But the current design of the agricultural system is not fixed. Witness, for example, the dramatic increase in soybean production, shown in Table 1: from 10.2 million acres in 1944 to 63.3 million acres in 1978. By assuming a similar level of crop substitution in the present system, to crops (such as sugar beets) having a high output of fermentable carbohydrates relative to protein, then the potential for ethanol production is greatly increased above what could be expected from corn and other grain crops alone. Table 2 compares the composition of the current livestock feed system to an example system in which corn and sugar beets are fermented to produce 35 billion gallons of ethanol (about one third of the demand for gasoline). In addition, enough livestock feed is produced from the corn and sugar beet fermentation residues, hay, pasture and corn cobs to match the amounts of digestible protein and total digestible nutrients currently consumed by livestock (see Commoner, 1980 and Carlson et al., 1980 for details).

In the example system described in Table 2, the land base consists of 262 million acres currently devoted to domestic livestock feed production, plus 38 million acres of idle and cover crop land. It does not include any of the acreage currently devoted to production of export crops. Also, the example system does not rely on expansion of intensively cultivated row crop acreage to marginal, highly erosive land. In their technical memorandum on Gasohol, the Office of Technology Assessment (1979: 37-44) concluded that intensive cultivation of marginal land for energy crop production is one of the most potentially severe environmental impacts of an expanded national ethanol program.

There are, however, environmentally benign ways to utilize marginal land for feed and fuel production. OTA (1979: 40) discusses the use of soil conserving forage grasses (perennial close-grown crops), but conversion of these crops to ethanol requires development of lignocellulosic technology. Tree crops are an attractive possibility because they actually improve the resistance of marginal land to soil erosion, yield an annual crop of pods high in fermentable sugar, and are compatible with pasture production. A more detailed examination of their value as a feedstock for ethanol production is outlined below.

Ethanol Production from Honeylocust Pods

Relative to other possible feedstocks for ethanol production, the honeylocust (*Gleditsia triacanthos*) offers the following major advantages:

1) Adaptability. In discussing the merits of the honeylocust, Smith (1953) states that "...some strain of this tree will certainly thrive in 90 percent of the area of the U.S., except the really arid lands." Other types of sugar pod-bearing trees, such as mesquite (*Prosopis juliflora*), are adaptable to arid regions.

2) Compatability with pasture production. With proper tree

Table 1

U.S. HARVESTED ACREAGE OF

CORN AND SOYBEANS, 1924-1978

Year	Corn (10^6A)	Soybeans (10^6A)
1924	100.4	0.4
1929	97.8	0.7
1934	92.2	1.6
1939	88.3	4.3
1944	94.0	10.2
1949	85.6	10.5
1954	80.2	17.0
1959	81.9	22.6
1964	65.4	30.8
1969	63.2	40.9
1974	76.7	52.4
1978*	75.1	63.3

*Estimated

Sources: USDA, Agricultural Statistics, 1978 for 1924-1974. USDA, Agricultural Outlook (September, 1978) for 1978.

Table 2

LIVESTOCK NUTRIENT PRODUCTION

Current Food System

Livestock Feed	Land (10^6A)	Dry Matter (10^6T)	Digestible Protein (10^6T)	Total Digestible Nutrients (10^6T)	Ethanol (10^9Gal)
Soybeans	21	23	10.7	19.9	
Grain	76	95	8.8	103.5	
Silage	14	38	1.7	26.4	
Hay[1]	61	123	12.9	73.8	
Pasture	84	148	13.8	100.2	
	262	427	46.2	323.8	

An Example Food and Fuel System

Livestock Feed	Land (10^6A)	Dry Matter (10^6T)	Digestible Protein (10^6T)	Total Digestible Nutrients (10^6T)	Ethanol (10^9Gal)
Beet Stillage	40	36	4.0	27.3	16.2
Beet Pulp		44	2.0	33.1	
Grain Stillage	115	59	15.8	64.6	18.8
Corn Cobs		34	0.0	17.1	
Hay	61	123	12.9	73.8	
Pasture	84	148	13.8	100.2	
	300	444	48.5	316.1	35.0

Sources: U.S. average crop yields and livestock feed consumption from cropland (excludes range and permanent pasture) for 1974-76 (years of low grain yields) in USDA, Agricultural Statistics, 1977. Digestible nutrients of feeds from Frank B. Morrison, Feeds and Feeding, 22nd ed. (Clinton, IA: The Morrison Publishing Co., 1959).

spacing, Zarger and Lutz (1961) report that honeylocust (Millwood variety) can be planted on pasture land without reducing grass yields. The open canopy of these trees permits significant light penetration, while the moderate amount of shading they do provide can actually improve pasture production during very hot weather. Land previously producing only pasture can also yield pods with a high sugar content.

3) Soil conserving. By their very nature, tree crops are soil conserving. They can be planted on stoney, wet, or steeply sloped land and actually improve resistance to soil and wind erosion, and at the same time yield a valuable annual crop.

The principal disadvantages of honeylocusts for ethanol production are:

1) Difficulty of low cost harvesting. Tree crops such as the honeylocust typically release their pods over an extended period of time, and often will not release them at all in some years. This is one of a number of factors which makes mechanical harvesting very difficult. There is, however, significant room for selection and genetic improvement over wild varieties.

2) Low per acre yields. A yield for honeylocust pods of 1.25 tons of dry matter (DM) per acre is average for the data reported by Smith (1953). This, in turn, would yield about 81 gallons of ethanol and 0.71 tons (100% dry matter) of fermentation residue per acre (see below for a discussion of how these yields were derived). As Table 3 indicates, these yields are quite low relative to crops such as corn (225 gallons of ethanol and 0.70 tons of stillage per acre) and sugar beets (420 gallons of ethanol and 3.95 tons of stillage--including beet tops --per acre). For this reason, tree crops such as the honeylocust are not likely to be used on land which can sustain high yielding sugar and starch row crops (unless conventional soil conserving tillage practices prove inadequate to control the erosion associated with row crops).

Even though the per acre yield of ethanol and livestock feed from honeylocust pods is relatively low, the fact that they could be planted on marginal land makes their potential aggregate contribution significant. Consider, for example, the prospect of planting honeylocusts on the 83 million acres of land currently devoted to cropland used only for pasture (USDA, 1979): approximately 6.7 billion gallons of ethanol could be produced annually, plus 59 million tons (100% DM) of livestock feed. To these figures can be added the probable gains in yield (due to genetic selection) above the ones reported by Smith (1953), plus the marginal land available in addition to cropland pasture.

Economics of Ethanol Production from Honeylocust Pods

Whether or not ethanol production on the order of 6.7 billion gallons per year is ever achieved depends mainly on the relative profitability of using honeylocust pods as a feedstock. The data needed to determine profitability are largely unavailable. Nevertheless, an approximation can be made of the price ethanol producers would be willing to pay for honeylocust pods, relative to other starch and sugar feedstocks. To do so, the following data must be established: 1) the yield of ethanol and stillage, and 2) the value of the stillage coproduct as a livestock feed.

Table 3

REPRESENTATIVE ETHANOL AND STILLAGE YIELDS FOR SELECTED FEEDSTOCK CROPS[1]

	Ethanol (anhydrous gallons)		Stillage (dry matter)	
Feedstock Crops	Per fresh weight ton	Average per acre	Pounds per fresh weight ton	Average tons per acre[2]
Sugar Crops:				
Sugarbeets[a]	22	420	100	1.00(3.95)
Sweet (sugar) sorghum[b]	15	280	220	2.05
Sweet (syrup) sorghum[b]	13	340	240	3.14
Sugar cane[a]	15	623	200	4.00
Jerusalem artichokes[c] (branching tuber)	21	480	100	1.14(4.68)
Fodder beets[d]	18	950	115	3.03(?)
Starch Crops:				
Corn[e]	93	225	580	0.70
Sorghum[e]	93	135	540	0.39
Wheat[e]	93	95	620	0.33
Potatoes[a]	23	280	76	0.46
Sweet potatoes[a]	34	190	92	0.26

Notes:

1. These data are to be regarded as approximations only; significant variations can be expected depending on the feedstock composition, the efficiency of conversion and recovery of products, and crop yields. For the starch crops, the yield data are generally based on practical experience, usually of the beverage alcohol industry. For the sugar crops, the yield data, as cited in the recent literature (see sources listed below) are typically calculated from the crops' fermentable sugar content, since very few fermentation tests have been done as yet with these crops.
2. Numbers in parentheses also indicate the additional yields of crop dry matter (e.g., sugarbeet tops) which can be used for livestock feed, but is not directly involved in the ethanol conversion process.

Sources:

a. Portola Institute. Energy Primer. Friche-Parks Press, Inc., Fremont, Cal. (1974).
b. Nathan, R. A. Fuels from Sugar Crops, DOE Critical Review Series. NTIS # TID-22781 (1978).
c. Staufter, M. D., et al. Jerusalem Artichoke. Agriculture Canada, CDA Research Station (March 1975).
d. Earl, W. B., and Brown, W.A.N. "Alcohol Fuels from Biomass in New Zealand--The Energetics and Economics of Production and Processing," Alcohol Fuels Technology Third International Symposium, pp. 1-12, Asilomas, Cal. (May 28-31, 1979).
e. Solar Energy Research Institute. Fuel from Farms--A Guide to Small-Scale Ethanol Production, SERI, Golden, Co. (1979).

Figure 1 outlines a representative scheme for processing honeylocust pods. Using data on the nutrient composition of the pods (see Table 4), the fermentable solids content (assumed to be primarily sucrose) was estimated at 46.4 percent on a dry weight basis. The yield of ethanol and stillage from the dry matter portion of the honeylocust pods was then calculated by assuming that: 1) the conversion efficiency of fermentable solids to ethanol is 86 percent of the theoretical maximum; this figure is used by Lipinsky, et al. (1976: 69) and the Davy McKee Corporation (1980: 70); 2) 5.4 percent of the fermentable solids is converted to recoverable yeast cells, since yeast recycling is not advisable (Lipinsky, 1976: 68-70); 3) competing microorganisms consume 1.0 percent of the fermentable solids; and 4) the recovery of stillage solids during concentration to a storable level is 95 percent efficient (a mass balance of the corn to ethanol process described in Katzen (1978) gives about the same efficiency).

The results are shown in Figure 1. For every one ton (100% DM) of honeylocust pods, 64.9 gallons of 200° ethanol are produced, plus 1133.0 pounds of stillage, 4.2 percent of which are yeast solids. Note that these yields are based on one ton of dry matter, but that honeylocust pods are typically harvested at 50 percent moisture.

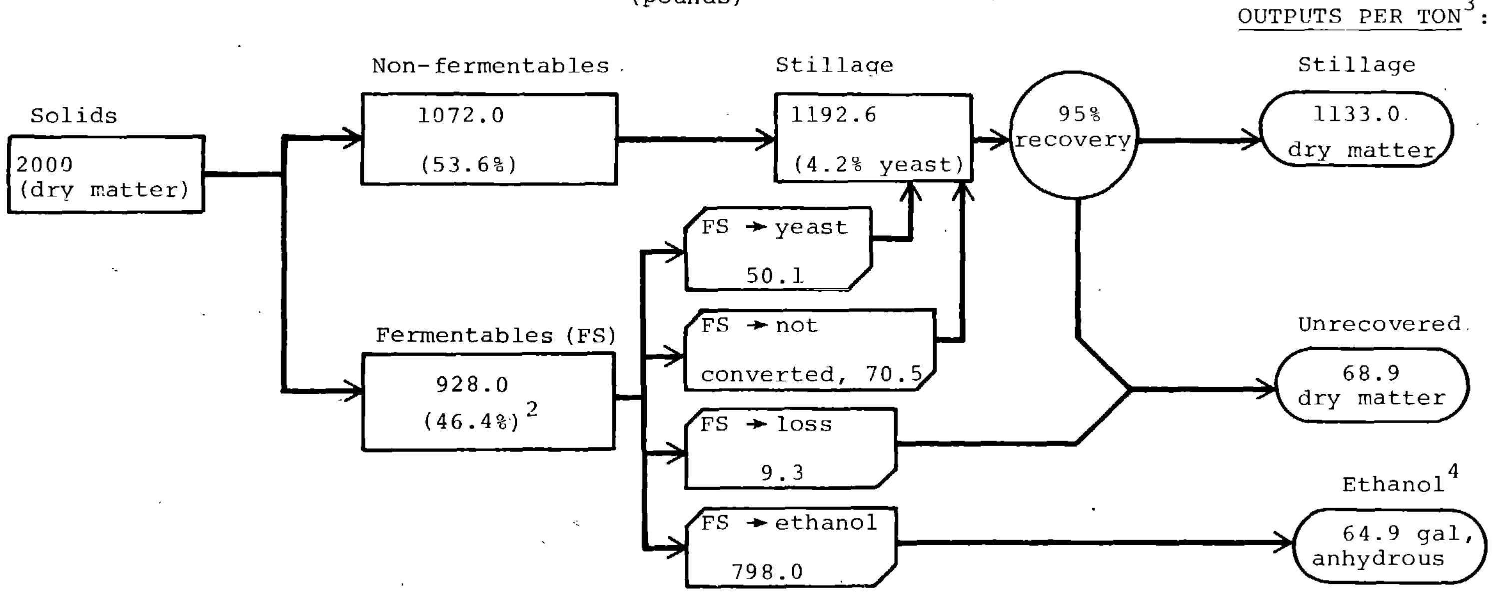
An estimate of the feeding value of the stillage coproduct can be made from the nutrient composition of the unfermented pods, shown in Table 4. Except for the fermentable solids content, the data were taken from the National Academy of Sciences (1971: 381). Fermentable solids content was estimated by taking the difference between the nitrogen-free extract (64.6%) and crude fiber (18.2%). The fermentation process converts almost all of the fermentable solids to ethanol, carbon dioxide, and yeast cells, but the other major components of the pod--fiber and protein--remain unaffected, so that their concentration increases in proportion to the decrease in fermentable solids. On this basis, the estimated composition of honeylocust pods after fermentation is given in Table 4. The total digestible nutrients (TDN) value is assumed to decrease in the same proportion as from corn grain (91.5% TDN) to corn distillers dried grains with solubles (DDGS, 83.5% TDN).

Given the approximate nutrient composition of the stillage, its economic value can be estimated. The data in Table 4 indicate that fermented honeylocust pods are very close in composition to alfalfa hay. Both are high in fiber, and relatively high in protein. It appears that fermented honeylocust pods may have a slightly higher TDN value than alfalfa hay, but the TDN figure is considerably more uncertain than the fiber and protein values. Thus, for the purpose of this analysis, it was assumed that fermented honeylocust pods have a feed value (and therefore economic value) equivalent to alfalfa hay. As of September 15, 1980, the national average price received for alfalfa hay was \$75.60 per ton (90% DM). (There is considerable variation in hay prices from state to state, and from region to region. Because of the high transport costs associated with hay, its markets are very localized). This was the price assigned to the honeylocust stillage. Given the ethanol and stillage yields outlined in Figure 1, and the stillage value discussed above, the price at which honeylocust and corn (at \$3.00

Figure 1

REPRESENTATIVE PROCESSING OF HONEYLOCUST PODS[1]

(pounds)



NOTES:

1. Compositional data are from National Academy of Sciences (1971: 381) for <u>Gleditsia triacanthos</u>, including seeds.

2. Derived by assuming: FS = (nitrogen-free extract) – (crude fiber). At 50% moisture, fresh weight basis, this corresponds to 23.2% sugar in the pod, a conservative value relative to others reported for 'Calhoun' and 'Millwood' varieties (Santamour, 1978).

3. See text for discussion of assumptions used in conversion efficiencies.

4. $\dfrac{(798.0 \text{ lbs. FS}) \times (0.538 \text{ lb. EtOH/lb. FS})}{6.62 \text{ lbs. EtOH/gal}}$

Table 4

NUTRIENT COMPOSITION DATA

	Honeylocust Pods, with Seeds, before Fermentation (1)	Honeylocust Pods, with Seeds, after Fermentation (2)	Alfalfa Hay (3)
International Feed Number	4-08-446	-	1-00-078
Crude fiber (% of DM)	18.2	31.9	30.6
Crude Protein (% of DM)	10.5	18.4	17.0
Digestible Protein (4) (% of DM)	5.7	10.0	9.6
Total Digestible Nutrients (4) (% of DM)	60.7	55.4	44.5
Fermentable Solids (% of DM)	46.4	3.5	-

NOTES:

1. Data are from the National Academy of Sciences (1971: 381); fermentable solids assumed to be equal to the nitrogen-free extract minus the crude fiber.
2. Crude fiber and crude protein are assumed to increase proportionately with the decrease in fermentable solids; digestible protein is assumed to be in the same ratio as in the unfermented pods; TDN is assumed to decrease in the same proportion as the decrease which occurs from corn grain to DDGS; the remaining amount of fermentable solids reflects incomplete conversion.
3. Data are from the National Academy of Sciences (1971: 11).
4. Data shown are averages for cattle and swine.

per bushel) are equivalent as feedstocks was calculated at 4.25¢ per pound (100% DM) of pods or about $86 per ton of pods at 100% dry matter. The production costs used to calculate this figure are shown in Table 5. For corn, the costs were taken from Raphael Katzen's (1978: 108) base case design of a 50 million gallon per year plant, using coal for boiler fuel. Katzen's (1978) cost data for fixed charges, raw materials, labor, electricity, and fuel were updated to 1980 dollars using the U.S. Department of Labor's Producer Price Indexes, for 1978 and May 1980. The price of corn was set at $3.00 per bushel, and DDGS at $144 per ton. (Katzen's corn and DDGS prices are lower, but their relative prices were held constant). The net production cost, using corn as a feedstock, is $1.141 per gallon of anhydrous ethanol produced.

For honeylocust pods, all production costs except the feedstock, were assumed to be the same as for Katzen's (1978: 159) design of a 50 million gallon per year plant running on 50 percent sweet sorghum and 50 percent corn. The value of honeylocust pods for ethanol production was calculated according to equation (1):

$$MHC = NPC + CC - X, \tag{1}$$

where MHC = maximum honeylocust cost, $/gal EtOH
NPC = net production cost, $/gal EtOH
CC = coproduct credit, $/gal EtOH; and
X = fixed charges + raw materials + labor + electricity + fuel + miscellaneous, $/gal EtOH.

The net production cost (NPC) was set at $1.141 per gallon of ethanol, the cost for a corn based plant. The coproduct credit (CC) was calculated at $0.733, based on a yield of 19.4 pounds (90% DM) per gallon of ethanol and $75.60 per ton (equivalent to alfalfa hay, 90% DM basis). All other costs (X) were computed to equal $0.560 per gallon of ethanol, by updating Katzen's (1978: 159) data. Because 30.8 pounds (100% DM) of pods are required to produce one gallon of ethanol, the resultant maximum cost of honeylocust pods (MHC) equals $1.314. This is equivalent to the honeylocust pods having a value of 4.26¢ per pound (100% DM), or about $86 per ton at 100 percent dry matter.

This result should be regarded as very tentative, since most of the data upon which it is based are speculative. However, it does serve to indicate the economic value of honeylocust pods to the farm producer. Unless production costs are lower than $86 per ton (100% DM), or about $108 per acre (at 1.25 tons/acre), honeylocust trees will not be worthwhile to invest in, at least from the standpoint of ethanol production.

Figure 2 shows how sensitive the above results are in terms of the economic value of the honeylocust stillage. The solid line gives the variation in the value of honeylocust pods versus the value of the stillage. Suppose, for example, the stillage value is one half of that of alfalfa hay (i.e., $37.80 per ton at 90% DM instead of $75.60); then honeylocust pods would be worth 3.07¢ per dry pound ($62 per ton, 100% DM) relative to corn as an ethanol production feedstock, a 39 percent

Table 5

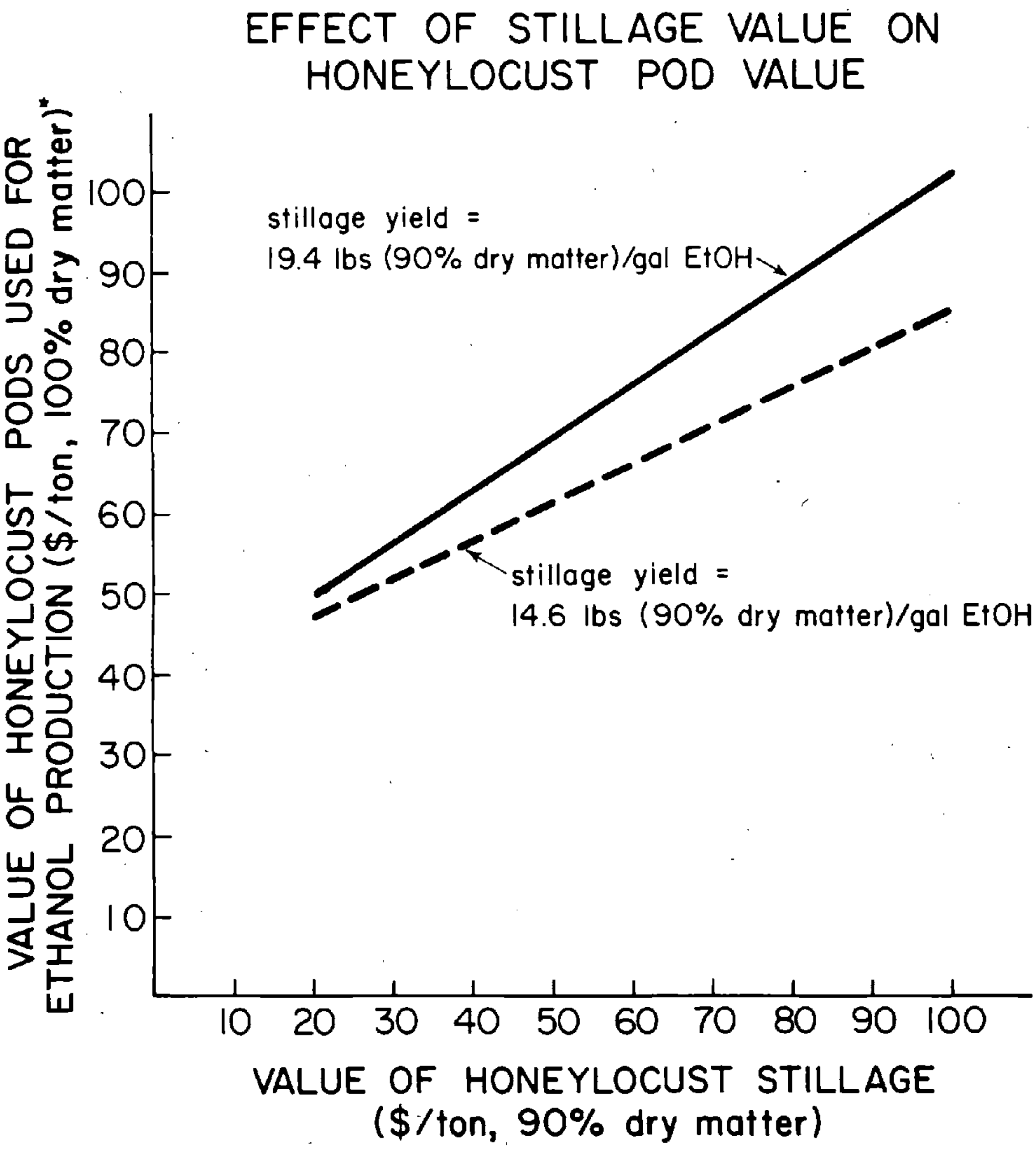
ETHANOL PRODUCTION COSTS BASED ON CORN AND HONEYLOCUST

	Corn (1) ($/gal EtOH)	Honeylocust (2) ($/gal EtOH)
Fixed Charges (3)	0.166	0.263
Raw Materials	0.022	0.016
Labor	0.087	0.090
Electricity	0.046	0.031
Fuel (coal)	0.052	0.052
Feedstock (4)	1.166	1.314
Miscellaneous	0.102	0.108
Total Production Cost (TPC)	1.641	1.874
Coproduct Credit (5) (CC)	-0.500	-0.733
Net Production Cost (6) (NPC)	1.141	1.141

NOTES:

1. Data are from Katzen (1978: 108), updated to 1980 dollars using the U.S. Department of Labor's Producer Price Indexes, for 1978 and May 1980.
2. Data are assumed to be the same as Katzen's (1978: 159) sweet sorghum and corn facility, except for the feedstock cost.
3. Included is an opportunity cost of capital of 6%.
4. Corn price is set at $3.00 per bushel; the honeylocust feedstock cost is derived, assuming equal NPCs for both plants.
5. DDGS price is set at $144/ton (90% DM); honeylocust stillage is assumed to equal alfalfa hay, at $75.60/ton (90% DM).
6. The NPC for honeylocust pods is set equal to the NPC for corn in order to derive the maximum value of honeylocust pods as a feedstock for ethanol production, relative to corn.

Figure 2



Relative to corn, at $3.00 per bushel

decrease. The dashed line on Figure 2 is for the case in which the actual yield of stillage is 75 percent lower than the 19.4 pounds (90% DM) calculated from Figure 1.

Conclusions

1) About 35 billion gallons of ethanol could be produced each year from agricultural crops in the United States without reducing the availability of feed for domestic livestock production or expanding row crop cultivation to highly erosive marginal land. An extensive amount of crop substitution on land currently in row crop cultivation would be required. Tree crops are not likely to be a part of the substitution on high quality land because of their relatively low yield of ethanol per acre.

2) Honeylocusts could extend ethanol and livestock feed production to marginal land and at the same time improve resistance to soil erosion. Even though per acre yields are low, there is enough cropland pasture in the United States to support production of about 6.7 billion gallons of ethanol per year from honeylocust pods, plus 59 million tons of 18 percent protein livestock feed.

3) A preliminary economic analysis indicates that honeylocust pods are worth up to $86 per ton (100% DM) as a feedstock for ethanol production relative to corn at $3.00 per bushel. This result is based on a) calculated yields of 64.9 gallons of ethanol and 17.5 pounds of stillage (100% DM) per dry ton of honeylocust pods; and b) a derived nutrient composition of the honeylocust stillage which suggests that it is roughly equivalent to alfalfa hay, especially in terms of fiber and protein.

4) Refined economic evaluations can be made if an extensive research program is initiated. The major elements of such a research program should include, with respect to ethanol conversion:

a) Determination of ethanol and stillage yields at the laboratory and pilot plant scale, from a variety of tree crops;

b) chemical analysis of the stillage, and eventually feeding trials;

c) analysis of the effects of storage on the percentage of fermentable sugars in tree crop pods;

d) evaluation of using tree crops as feedstocks for on-farm ethanol conversion; and

e) determination of the production costs (e.g., fixed charges, raw materials, labor, and utilities) associated with using tree crop pods for ethanol production.

Considerable research is also needed to assess all of the production costs associated with planting, cultivating, and harvesting tree crop pods.

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WOODY TROPICAL LEGUMES: POTENTIAL SOURCES OF FORAGE, FIREWOOD, AND SOIL ENRICHMENT.

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ABSTRACT.

Insufficient forage for livestock, lack of firewood for man, and diminishing soil fertility for agricultural production are three common problems in tropical areas. The fact that woody legumes are abundant and occasionally utilized by the rural populations in Mexico suggested that these species might be used on a more widespread basis as partial solutions to one or more of the above problems. Consequently, eleven species of woody legumes, found in the state of Veracruz, Mexico, were compared for their ease of propagation from seeds and cuttings, proximate and toxicological characteristics, nitrogen fixing ability, and growth under two climatic regimes. Results suggest that six of these species possess multi-use potential with respect to the above three problems.

INTRODUCTION.

Livestock in Mexico annually require more protein than the combined yearly national production for both man and animals (Quintero and Powers, 1976). At present, the gap between forage supply and demand is filled by importation. However, importation is neither economically feasible for small farmers nor nationally acceptable as a long-term solution to the problem of foodstuff scarcity.

Intimately linked to the problem of forage production is fertilizer insufficiency. The demand for greater agricultural production, coupled with the low nutrient status of many tropical soils, has led to a marked increase in fertilizer use (Brill, 1979). However, factors of rising cost, limited supply, and poor distribution networks result in fertilizer scarcity in remote rural areas, where it is most needed to improve the production of subsistence farming.

In addition to the above, the rural poor also lack sufficient firewood for cooking and at high altitudes, heating. Recent figures indicate that the annual demand for fuelwood by the rural population of Mexico exceeds 20 million m^3 (Villa-Sales, 1978). However, due to a law banning tree cutting, little firewood is available to the rural inhabitant. Only large forest industries are able to obtain governmental permits to harvest wood, which they market as pulp or timber. Since cooking fuel is vital to the rural poor, they are often forced to illegally cut trees.

The three problems discussed above; scarcity of forage, fertilizers, and firewood, are not unique to Mexico but occur throughout the tropics. Technological solutions to these problems certainly exist but are usually beyond the economic means of those most severly affected, the rural poor. Consequently low energy-intensive alternatives are urgently needed. Some examples of the latter would be to use endemic vegetation, particularly fast growing trees and shrubs, more extensively for forage, or to incorporate a natural fertilizing mechanism, such as biological nitrogen fixation, into existing agricultural practices. Similarly, "living fences", which are comprised of fence posts of sprouted tree cuttings, could be more widely used to enclose agricultural fields and pastures, and be periodically coppiced for firewood.

The three low-technology solutions proposed above are particularly attractive for several reasons. They are low cost, utilize endemic vegetation which is adapted to existing climatic conditions, and may be familiar to the local populace. For example, several, of the over 600 species of woody legumes found in the state of Veracruz, Mexico, are already used locally by farmers for "living fences" and/or food for man and animals (Table 1). This fact, coupled with the occurrence of nitrogen fixation in the legume family, suggested to us that woody legumes might be utilized on a more widespread basis as partial solutions to one or more of the above problems.

OBJECTIVES AND METHODOLOGY.

Given the urgent need for low-technology solutions to the problems of forage, firewood, and fertilizers, we undertook a study to determine the multi-use potential of woody legumes in the state of Veracruz with respect to these three problems. In September 1979 we selected the following eleven species for an initial screening study: *Acacia pennatula* (Schlechtendal & Cham.), *Albizia lebbek* (L.), *Caesalpinia cacalaco* (Humb. & Bonpl.), *Cassia fistula* (L.),

Erythrina americana (Miller), *Gliricidia sepium* (Jacq.), *Inga jinicuil* (Schl.), *Parkinsonia aculeata* (L.), *Pithecellobium dulce* (Roxb.), *Pithecellobium flexicaule* (Benth.), and *Pithecellobium lanceolatum* (Humb. & Bonpl.). These species were selected because they occur in the state of Veracruz, were not being studied by other institutions in Mexico, and all had at least one known use either in Veracruz or in other tropical areas (Table 1).

The screening study was comprised of the following investigations:

1. A study of the present distribution and use of each of the eleven species in Veracruz.
2. A comparison of methods for breaking seed dormancy, ease of propagation from seeds and cuttings, and growth of seedlings under two climatic regimes.
3. An investigation of the nitrogen fixing capacity of each species and quantification of its annual fixation under field conditions.
4. Proximate and toxicological analyses of selected plant parts.
5. A determination of firewood characteristics and annual fuelwood production.

Based on the results of these five studies, the species with the highest multi-use potential will be tested in long-term field and animal feeding trials. During the field trials, screening of a second group of woody legume species will begin. Our plan, at present, is to screen as many species as is realistically possible, but to field and animal test only those species with the highest multi-use potential. To date, we have partially completed the initial screening study on the first eleven species.

RESULTS.

DISTRIBUTION STUDY.

The eleven species selected come from parts of Veracruz with markedly different climates. For example, *P. aculeata* occurs in the hot-arid northern part of the state, *G. sepium* is found in the hot-humid coastal area, and *E. americana* is common in the cool-humid western highlands.

Interestingly, the widespread distribution of several species appears to reflect the amplitude of their use by man. For example, *E. americana* is abundant in the central western uplands, where it is also widely used as a "living fence" (Figure 1). In addition, it is occasionally utilized

as a "living fence" near the coast and also occurs in the remanent rainforest in southern Veracruz. *A. pennatula* is common in the center of the state from the western highlands almost to the coast. This area is also where it is extensively employed as a pasture shade tree. Similarly, *G. sepium* exhibits a distribution which coincides with the areas of the state where it is used as a "living fence". Lastly, *I. jinicuil* is planted for shade in coffee plantations and is found almost exclusively in the central upland coffee growing region. As far as we have been able to determine, natural stands of these four species, within or outside their area of utilization by man, are quite rare. In contrast, the other seven species studied have more restricted distributions and are also less widely used by man.

GERMINATION-PROPAGATION-GROWTH.

Five methods of breaking seed dormancy were compared: 1. soaking in concentrated sulfuric acid, 2. soaking in hot water, 3. puncturing the seed coat, 4. filing away part of the seed coat, and 5. no treatment. Although soaking in sulfuric acid resulted in highest percent germination, puncturing the seed coat proved to be the most effective, simpliest, method of breaking seed dormancy readily available to the rural farmer (Table 2). Two of the eleven species, *I. jinicuil* and *G. sepium*, exhibited good germination without treatment.

Seedlings of all species, with the exceptions of *P. dulce* and *P. flexicaule* whose seeds failed to germinate, were planted in plastic bags containing 7 kg soil. Half the bags were moved to the INIREB coastal field station at Morro de la Mancha where the mean annual temperature is 24°C and rainfall, 1350 mm (Garcia, 1970). The other half of the bags were placed in the INIREB Botanical Garden in Xalapa; elevation 1380 meters, mean annual temperature, 19°C, and rainfall, 1957 mm (Garcia, 1970). At the same time, 100 cuttings, 50 cm long by 3 cm in diameter, from each of ten species were planted, half at Morro de la Mancha and half in the Botanical Garden. Growth of seedlings and cuttings in both locations was observed periodically for 7 months.

Not all of the species in the seedling experiment grew at both elevations. Seedlings of *C. fistula* and *A. lebbek* failed to produce more than four leaves at 1400 meters. Thus, growth for these species at this elevation is reported as negative (Table 2). All *I. jinicuil* seedlings died within two weeks of their arrival at the coastal field station. These growth responses reflect the distributional limitations

of these species.

Seedling growth of the other six species that grew at both elevations was consistently greater at sea level. Better growth at the lower elevation was expected for species that are normally found in hot-dry or hot-humid areas, for example, *P. aculeata*, and *G. sepium*. However, growth of two upland species, *E. americana* and *A. pennatula*, was also greater at sea level than at 1400 meters. These results suggest that the latter two species might be successfully grown in other regions than those in which they presently occur.

Only *E. americana*, *G. sepium*, *C. cacalaco* and *P. lanceolatum* cuttings sprouted (Table 2). These species are also the most common ones encountered in "living fences" in Veracruz. Of these four species, only *C. cacalaco* failed to grow at both sea level and 1400 meters. As was observed for the seedling experiment, growth of cuttings was greater at the lower elevation. Survey data had revealed that *P. aculeata* and *A. pennatula* are also used for "living fence" in Veracruz (Table 1). However, whether cuttings or seedlings are used to produce "living fences" of these two species is unknown.

NITROGEN FIXATION

Nitrogen fixed by tree legumes becomes available for uptake by surrounding vegetation when leaves and nodules decompose. Therefore, foliage of tree legumes is used for green manure in many tropical areas (N.A.S., 1979). However, whether agricultural systems with tree legumes benefit significantly from fixation by these species depends on the amount of nitrogen fixed, and the nitrogen demand of the legume and the crop plant. In spite of the potential importance of this natural fertilizing mechanism, little data exists on nitrogen fixation by woody legumes.

Consequently, the nitrogen fixing activity of seven-month old woody legumes was determined using the acetylene reduction technique (Hardy et al., 1968). Assays were performed on seedlings grown at sea level of all species, except *P. dulce*, *P. flexicaule* and *I. jinicuil* which either did not germinate or survive at this elevation.

Five of the eight species assayed exhibited nitrogen fixing activity, which ranged from a high of 44 μ moles N_2 fixed g^{-1} nodules hr^{-1} for *G. sepium* to a low of about 9 μ moles N_2 fixed g^{-1} nodules hr^{-1} for *A. lebbek* (Table 3).

In a subsequent study, nodule biomass and "in situ" nitrogen fixing activity were measured in stands of *I. jinicuil*, *A. pennatula*, and *G. sepium*. These data were used to calculate the amount of nitrogen fixed annually by these species on an areal basis. (Table 3).

Inga jinicuil is a common shade tree in coffee plantations in the Xalapa area. In one such plantation, annual fixation by *I. jinicuil* equaled 35 kg N_2 ha^{-1} yr^{-1}, which is approximately 22 to 78% of the amount of nitrogen applied annually via fertilizers (Roskoski, 1981). Interestingly, the area of the plantation with *I. jinicuil* trees also had higher coffee yields than sites in the same plantation with non-nodulated shade trees. However, whether the higher coffee production in the *I. jinicuil* site is wholly or partly due to the added nitrogen from fixation has yet to be determined.

Calculated fixation in a 20-year-old *A. pennatula* stand was approximately 34 kg ha^{-1} yr^{-1}, and in the *G. sepium* stand, with 2700 stems ha^{-1}, 13 kg ha^{-1} yr^{-1} (Table 3). Both areas were formerly cultivated but now contain successional re-growth, dominated by the above species.

The magnitude of the nitrogen added annually via fixation in these three sites suggests that fixation by tree legumes could make a significant nitrogen input to an agro-ecosystem. However, intercopping studies are needed to assess the actual amount of nitrogen available to crop species from fixation by woody legumes.

PROXIMATE AND TOXICOLOGICAL ANALYSES.

Proximate analyses and determination of "in vitro" digestability are being conducted on flowers, seeds, pods, and leaves of all species. Results, to date, of these analyses are presented for seeds, leaves, and pods (Table 4, 5, and 6). Appropriate values for soybeans (*Glycine max*), alfalfa (*Medicago sativa*), and mesquite (*Prosopis juliflora*) are included in the tables for comparison.

Crude protein content was highest for *A. lebbek*, *E. americana*, *G. sepium*, and *P. flexicaule* seeds; *A. pennatula*. *A. lebbek*, *E. americana*, and *I. jinicuil* foliage; and *A. pennatula* and *P. aculeata* pods. Percent carbohydrate in seeds of eight of the 11 species was similar to, or higher than, that for soybeans, while carbohydrate levels in pods of

A. pennatula, *P. aculeata* and mesquite were similar. Although foliage of *E. americana*, *G. sepium* and *I. jinicuil* had the highest carbohydrate content of the 11 species tested, these values were below those reported for alfalfa. Only *I. jinicuil* and *P. lanceolatum* seeds; *A. pennatula*, *C. cacalaco*, and *G. sepium* foliage; and *C. cacalaco*, and *P. aculeata* pods had comparable or lower percent crude fiber than the reference species. "In vitro" digestability for all species ranged from 52 to 86% for seeds, 70 to 88% for foliage, and 74 to 98% for pods.

The above results indicate that several species have favorable nutritional characteristics. However, proximate analysis is only the first step in evaluating a potential forage plant. Palatability tests are also required before the efficacy of a species for forage can be assessed. Furthermore, legumes contain a wide array of secondary Compounds which may be toxic when present in high concentrations. Consequently, the same plant parts used for proximate analyses were also analyzed for alkaloids, saponins, tannins, phyto-hemagglutinins (lectins), trypsin inhibitors, and cyanogenic glycosides. Of the six types of compounds listed above, alkaloids, lectins, and trypsin inhibitors are considered particularly characteristic of the legume family. Results of these analyses indicate that no plant part of any of the eleven species contained cyanogenic glycosides. In addition, while every species contained at least one of the other five compounds in its seeds, leaves, or pods (Table 7), toxic levels of these substances were rarely encountered. Only *E. americana* and *I. jinicuil* seeds had prohibitively high levels of any of these substances.

FIREWOOD.

Studies comparing the caloric content and burning characteristics of wood of the eleven species are scheduled to begin in January 1981. However, several of the species being studied are already used, on a limited basis, for firewood. Wood coppiced from living fences of *G. sepium* and *P. lanceolatum*, as well as wood pruned from *I. jinicuil* shade trees in coffee plantations and *A. pennatula* trees in pastures are burned for fuel by the rural populace of Veracruz. Wood of the latter two species is also collected and sold in the local markets.

A study of wood production by *I. jinicuil* and *A. pennatula* to indicate that further utilization of these species for fuelwood is warranted. In a coffee plantation with 25-year-old *I. jinicuil* shade trees, at a density of 205 trees

ha^{-1}, basal area, 17.50 m^2, woody biomass equaled 75 metric tons ha^{-1}; while a 20-year-old *A. pennatula* stand with 6,200 trees ha^{-1}, basal area equal to 13.78 m^2, contained 53 metric tons of wood ha^{-1}. These values suggest that managing woody legumes for wood production may be a viable way to produce firewood.

DISCUSSION.

Based on the studies completed thus far, the following six species appear to have the greatest multi-use potential:

1. *Acacia pennatula.* This species is widely distributed in the state of Veracruz and can apparently grow in warmer areas than those in which it is presently found. It can be propagated from seeds but not from cuttings. *A. pennatula* is presently employed for shade in pastures and occasionally in coffee and cacao plantations (Chazaro, 1977). Annual nitrogen fixation in one *A. pennatula* stand equaled 34 kg N_2 ha^{-1} yr^{-1}. Seeds, leaves, and pods of this species do not contain high levels of toxic secondary compounds, and would appear to be, nutritionally, excellent forage material. With respect to forage yield, it has been estimated that annual pod production may equal 6.5 metric tons ha^{-1} (Chazaro, 1977). At present its wood is only used locally for fuel. However, its rapid growth rate, which in one stand led to a woody biomass accumulation of 53 metric tons ha^{-1} in 20 years, suggests that it may be worthwhile to manage this species for firewood production.
2. *Albizia lebbek.* Although recently introduced as an ornamental, and at present not widely distributed, *A. lebbek* appears to have high multi-use potential. Reports from other tropical areas indicate that this species is widely cultivated for fuel (N.A.S., 1979). We found that it can be propagated from seeds but grows poorly at high altitudes. *A. lebbek* fixes nitrogen, although annual fixation in a field setting has yet to be determined. Seeds, leaves, and pods contain high levels of crude protein, and moderate amounts of carbohydrate and crude fiber. Prohibitive levels of toxic compounds were not detected in any of the plant parts analyzed.
3. *Erythrina americana.* *Erythrina americana* is common in the upland regions of the state but apparently can also grow well at sea level. It can be easily propagated from either seeds or cuttings; the latter being used to construct "living fences". The flowers of this species are highly prized for their flavor and are sold in all local markets, thus constituting an additional source of income for the small farmer, who uses "living fences" of *Erythrina*. It fixed nitrogen but

its annual nitrogen input on a area basis is unknown. Although its seeds are rich in crude protein, they also contain extremely high levels of toxic compounds. This rules out the use of either seeds or whole pods as potential forage material. On the other hand, the levels of toxins present in the foliage do not contraindicate its use for forage. The wood of *E. americana* is light and porous and thus considered a poor source of fuelwood.

4. *Gliricidia sepium*. *Gliricidia sepium* is widely distributed in coastal, warm areas, and grows poorly at higher elevations. It can be easily propagated from seeds, which require no special treatment to break dormancy, or cuttings. The latter are used to produce "living fences" in coastal areas. Its flowers, like those of *E. americana*, are consumed locally but not normally sold in the markets. *G. sepium* fixes nitrogen, which in one stand equaled 13 kg ha^{-1} yr^{-1}. The seeds are high in crude protein, and foliage high in carbohydrates. Although levels of toxic substances in all plant tested were not prohibitively high, it has been reported that pods of this species are utilized by coastal inhabitants for rat poison. Wood coppiced from "living fences" is used as fuel but annual firewood production is unknown.
5. *Inga jinicuil*. The distribution of this species is limited to higher elevations. Its seeds germinate rapidly, which can make seed storage a serious problem. Annual nitrogen fixation in one coffee plantation with *I. jinicuil* shade trees equaled 35 kg ha^{-1} yr^{-1} which represented a sizeable nitrogen input to the coffee ecosystem. Since the succulent aril surrounding the seed is consumed, coffee workers collect and sell pods in the markets. Percent crude protein and carbohydrates are high and crude fiber and toxins low in *I. jinicuil* foliage. Despite an abundance of trypsin inhibitor in its seeds, cattle have been observed ingesting *I. jinicuil* pods. Woody biomass in a 25-year-old stand equaled 75 metric tons ha^{-1}, suggesting that it may be feasible to manage for firewood.
6. *Pithecellobium lanceolatum*. This species is restricted to warm tropical areas of the state. It can be propagated from seeds and cuttings, and is used together with *G. sepium* as a "living fence" in coastal areas. It fixes nitrogen and is used as fuelwood by rural inhabitants. Its seeds and foliage do not contain high levels of toxins nor are they particularly rich nutritionally. Never the less, this species is used as forage by rural inhabitants along the coast.

CONCLUSIONS.

The investigations completed, to date, suggest that 6 of

the original 11 species of woody legumes could be used for forage, firewood, and soil enrichment. However, this appraisal is based on laboratory analyses and limited field investigations. When the remaining studies that comprise the screening procedure are completed, one or several of the original 11 species will undergo extensive field and animal trials. Only then will we be able to determine if woody legumes represent viable solutions to the above three problems.

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Table 1. Uses of 11 species of woody legumes.*

SPECIES	Food**	Forage	Firewood	Living Fence	Green Manure	Medicinal	Shade for Crops	*** N_2 Fixation
Acacia pennatula		A	AB	A		B	A	
Albizia lebbek		B	B		B			+B
Caesalpinia cacalaco	2A			A				
Cassia fistula						B		—B
Erythrina americana	1AB			A	B	AB	AB	
Gliricidia sepium	1A	B		AB		B		±B
Inga jinicuil	3A		A			A	A	+A
Parkinsonia aculeata		B	AB	A		B		
Pithecellobium dulce	3A	AB	AB			AB		
Pithecellobium flexicaule	2B		AB					
Pithecellobium lanceolatum		A	A	A				

*A = in Veracruz
B = other areas

** Part consumed by man:
1 - flowers
2 - green pods
3 - succulent aril

*** + = fixes N_2
— = does not fix N_2

Table 2. Propagation and growth of woody legumes.

Species	B.D.*	Seeds 0m**	1400m	Cuttings 0m	1400m
A. pennatula	A	+	+	–	–
A. lebbek	NT	+	–	–	–
C. cacalaco	A	+	+	–	+
C. fistula	A	+	–	–	–
E. americana	A	+	+	+	+
G. sepium	B	+	+	+	+
I. jinicuil	B	–	+	NT	NT
P. aculeata	A	+	+	–	–
P. dulce	NT	NT	NT	–	–
P. flexicaule	NT	NT	NT	–	–
P. lanceolatum	NT	+	+	+	+

*Treatments for breaking seed dormancy:

A = scarification by puncturing the seed coat
B = no treatment
NT = not tested

**Seedlings and cuttings were grown at 0 and 1400 meters elevation.

+ = grew

– = didn't grow

Table 3. Nitrogen fixation in 9 species of woody legumes*.

Species	μ moles N_2 fixed g^{-1} nod. h^{-1}	kg N_2 fixed ha^{-1} yr^{-1}
A. pennatula	14.30 ± 2.20a 20.54 ± 2.77d	34 ± 7d
A. lebbek	8.60 ± 3.50a	
C. cacalaco	NN	
C. fistula	NN	
E. americana	13.00 ± 1.70a	
G. sepium	44.10 ± 14.90a 11.72 ± 2.57e	13 ± 3e
I. jinicuil	2.28 ± 0.34c	35 ± 7c
P. aculeata	NN	
P. lanceolatum	14.41 ± 3.80a	

***P. dulce* and *P. flexicaule* did not grow. All values shown are $\pm s_{\bar{x}}$.

[a]based on activity of 7-month-old seedlings.

[b]NN = not nodulated.

[c]based on nodule biomass and activity in a 25-year-old *I. jinicuil* stand.

[d]based on nodule biomass and activity in a 20-year-old *A. pennatula* stand.

[e]based on nodule biomass and activity in a *G. sepium* stand with a density of 2700 trees/ha.

Table 4. Proximate analyses of seeds of 11 species of woody legumes.*

SPECIES	% humidity	% ash	% Crude Protein	% Crude fat	% Crude Fiber	% Carbohydrates	% in vitro digestability
A. *pennatula*	8.49	4.85	29.16	4.18	18.40	43.49	85.83
A. *lebbek*	9.47	3.57	33.60	3.13	13.17	35.30	78.25
C. *cacalaco*	13.07	2.40	20.21	6.06	9.02	43.50	72.61
C. *fistula*	5.31	4.55	24.00	4.43	6.68	50.36	81.17
E. *americana*	11.63	4.59	36.56	20.07	8.20	19.95	70.50
G. *sepium*	11.93	1.90	33.00	16.50	9.07	27.60	52.42
I. *jinicuil*	5.37	2.36	28.74	2.82	1.65	59.06	68.03
P. *aculeata*	15.34	2.46	29.74	2.36	14.97	35.11	78.45
P. *dulce*	14.00	2.66	25.69	8.12	22.16	26.97	80.84
P. *flexicaule*	8.29	3.44	31.54	14.94	14.86	35.36	79.60
P. *lanceolatum*	13.99	1.90	18.90	1.03	2.99	61.19	66.31
Glycine max	0.00	5.50	39.00	19.60	4.70	35.50	

*Methods for proximate analyses from A.O.A.C. (1970), methods for "in vitro" digestability in monogastric animals from Oke et al. (1974).

Table 5. Proximate analyses of foliage of 11 species of woody legumes.*

SPECIES	% humidity	% ash	% Crude Protein	% Crude fat	% Crude Fiber	% Carbohydrates	% in vitro digestability
A. *pennatula*	18.61	4.40	23.67	2.23	18.61	32.48	86.28
A. *lebbek*	3.57	7.06	28.87	5.42	31.75	23.33	83.55
C. *cacalaco*	11.39	13.55	14.43	5.00	12.13	43.16	83.09
C. *fistula*	11.21	6.39	15.88	6.65	20.01	39.86	88.43
E. *americana*	11.47	9.95	26.09	8.38	31.71	49.24	74.26
G. *sepium*	11.96	12.09	19.92	2.34	11.04	42.65	69.69
I. *jinicuil*	5.80	5.80	20.34	2.00	20.02	45.95	71.20
P. *aculeata*	11.76	8.98	14.13	2.86	27.70	34.57	67.02
P. *dulce*	6.46	15.34	17.17	6.83	30.95	23.25	71.46
P. *flexicaule*	10.09	14.43	17.03	8.23	24.16	26.06	76.86
P. *lanceolatum*	8.93	15.20	17.46	5.93	23.59	28.89	82.20
Medicago sativa	0.00	8.10	34.70	2.30	17.90	54.90	

*For methods employed in the various analyses see Table 4.

Table 6. Proximate analyses for pods of four species of woody legumes.*

SPECIES	% humidity	% ash	% Crude Protein	% Crude fat	% Crude Fiber	% Carbohydrates	% in vitro digestability
A. pennatula	9.52	5.11	12.57	0.85	50.47	41.00	87.60
A. lebbek	6.99	5.47	17.86	2.60	45.08	22.00	76.56
C. cacalaco	12.77	3.11	7.84	3.86	1.51	70.91	98.00
P. aculeata	13.59	4.40	16.59	2.11	28.43	34.88	73.90
Prosopis juliflora	0.00	4.70	13.80	2.90	28.80	49.80	

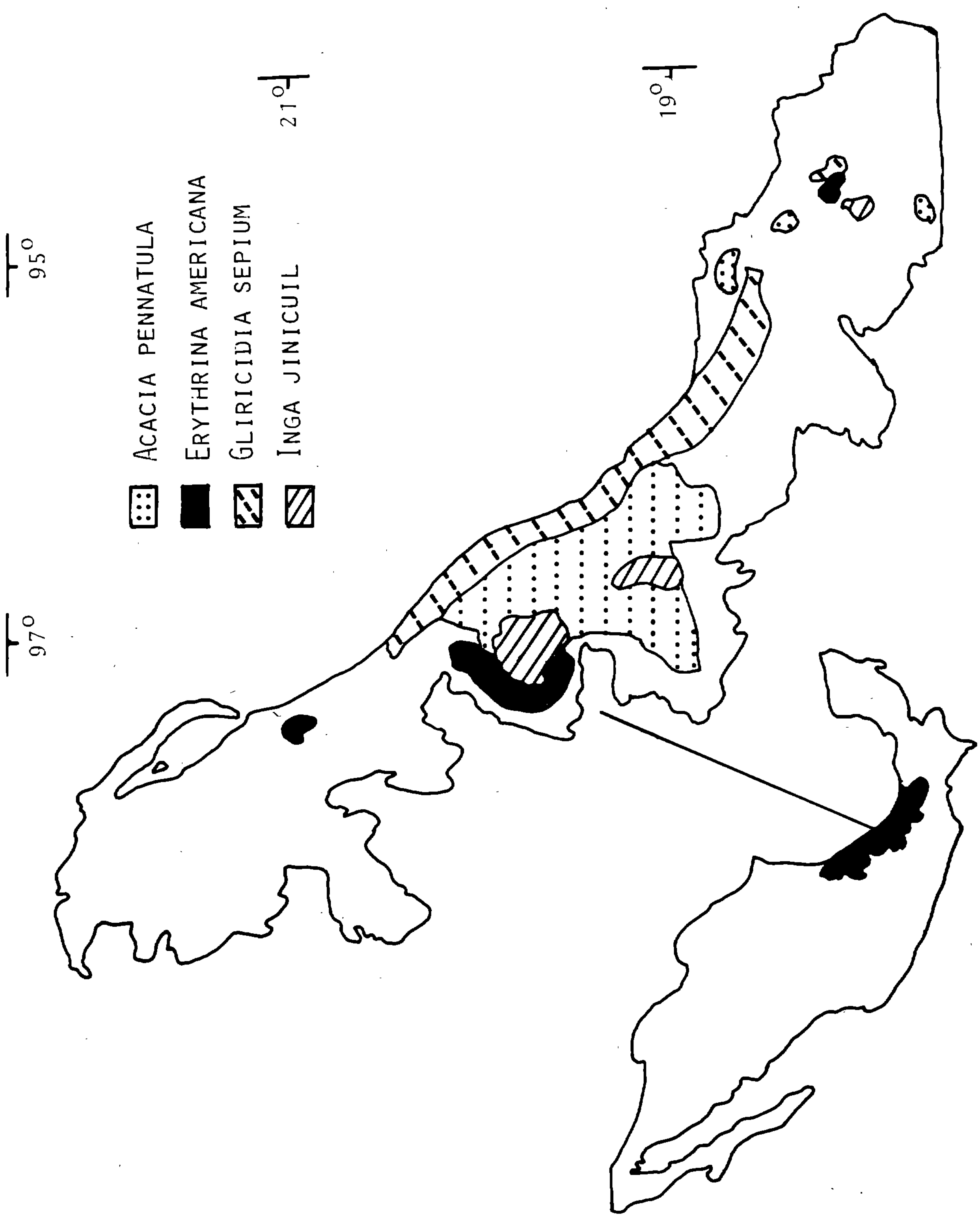
*For methods employed in the various analyses see Table 4.

Table 7. Toxicological analyses of seeds and foliage of 11 species of woody legumes.

SPECIES	SEEDS Alk.* (%)	Sap. (Qual.)	Tannins (g/100g)	Lectins (max. dil.)	Trypsin inhibitors (UTI)	FOLIAGE Alk. (%)	Sap. (Qual.)	Tannins (g/100g)	Lectins (max. dil.)	Trypsin inhibitors (UTI)
A. pennatula	—	+	—	—	11.30	—	—	3.0	—	33.60
A. lebbek	—	+	—	—	19.93	—	+	—	—	21.40
C. cacalaco	—	+	—	2	—	—	—	2.7	—	—
C. fistula	.01	—	—	1	—	—	+	—	—	—
E. americana	.42	+	—	5	218.4	.10	—	—	—	37.40
G. sepium	.10	+	—	—	—	—	+	—	—	—
I. jinicuil	.03	+	—	—	254.0	.04	+	2.0	—	—
P. aculeata	.12	+	—	—	—	—	+	—	—	—
P. dulce	.01	+	—	—	—	—	+	—	—	—
P. flexicaule	.01	+	—	—	91.2	.01	—	—	—	—
P. lanceolatum	.06	+	—	—	—	—	—	—	—	—

*Alkaloids determined by method of Jacob (1974); saponins determined by the method of Monroe et. al. (1952); tannins determined by the method of Price et. al. (1977); lectins determined by the method of Jaffe (1968); trypsin inhibitors determined by the method of Kakade (1969).

Figure 1. Map of Veracruz showing the distribution of four species of woody legumes, with insert indicating the location of Veracruz in Mexico.


97°
95°
21°
19°
Acacia pennatula
Erythrina americana
Gliricidia sepium
Inga jinicuil

MULTI-USE TREE CROPS IN SOLAR VILLAGES

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ABSTRACT

Annual tree products used as alcohol feedstocks will have their highest value when converted near their site of production to minimize transport costs.

The other energy benefits of tree use, including soil/water conservation and residential climate control, also have calculable energy values which are dependent on the nearness of the trees to their end use.

Careful biotechnical design of farm energy systems will integrate the energy benefits of both tree products and tree processes as closely as possible to the local communities, including urban landscapes and new solar villages.

The tree products which show the most promise as alcohol feedstocks are high-carbohydrate fruits or pods such as mesquite, carob, honey locust, acorns or persimmons - all of which have high alternative values as either livestock feeds or processed foods for people. Relatively long establishment periods for tree plantations make it likely that the market for such products will vary between alcohol feedstocks and livestock feeds in relation to shifts in energy and food prices. It is useful to consider a tree crop system which is designed to yield products for either alcohol or for livestock feed, depending on the market for each in any particular year. Such a system would assume the existence of an alcohol plant able to buy feedstocks and would generally favor storable tree crops rather than perishable fruits. If harvested as an alcohol feedstock, the crop would be harvested mechanically at one time or in successive sweeps and delivered to the plant. If treated as a hay/grain substitute, the crop could be foraged directly by livestock in the field or harvested, stored and marketed in competition with other more conventional feeds.

Net Energy of Alcohol Feedstocks

The economic viability of tree crop production for alcohol fuels depends on the harvest and transport of biomass, which tend to have relatively low energy densities. The energy required to move a load of biomass such as wood, charcoal, or crop residue may be equivalent to a sizable fraction of the energy content of the material. Energy

calculations can be helpful in identifying limits of transport where the net energy of a process approaches zero. Fuels with very high energy densities such as petroleum and coal are worth transporting across continents; alcohol is relatively energy-dense and is more economically transportable than the original feedstock. Thus it is preferable to convert the feedstock to alcohol as near to the point of production as possible.

Net energy analysis is useful as long as one remembers that not all energy forms are of equal quality, though they may be equal in quantity of energy units. For instance, a liquid fuel such as alcohol can provide mobility as an engine fuel; it may be socially worth ten times its energy value in wood, which cannot easily provide mobility, or worth a hundred times its energy value in solar heat, when mobility is the goal. After all, fuel alcohol is not sought as an end product, but as a means to an end, usually mobile engines. Alcohol fuel must therefore compete economically with alternative liquid fuels and even alternative transportation options, such as electric vehicles. These larger market factors ultimately constrain the viability of alcohol from tree crops more than mere technical feasibility.

Pest Control in Monocultures

Modern fruit and nut orchards require intense managment and pesticide treatments to control pests. This control effort is the ecological price of maintaining a monoculture. Commercial orchards typically contain several varieties of a single species, and are the nearest exmple of the kind of tree crop plantings envisioned for alcohol products. These monocultures are kept ecologically simple by frequent application of pesticides, fungicides, and herbicides. Recent ecological theory of pest management in polycultures indicates that epidemics of pests and diseases can be avoided by including many different plant species and a number of genetic varieties of each species. Further benefit can be obtained by including in the polyculture plant species which serve as habitat for beneficial organisms which assist in pest control (1). This ecological strategy is a permanent, low-maintenance alternative to frequent chemical control, and suggests a design strategy to be incorporated into tree crop plantations. If the plantation polyculture contains firewood, timber and other products for the local economy, it can maintain a degree of ecological stability at the same time (2).

Environmental Benefits of Trees

In addition to products, trees produce a number of well documented indirect benefits by their mere presence and growth. Trees have the effect of moderating climate, controlling erosion, filtering air and water, reducing noise and providing recreational space (3). Each such benefit has a calculable economic and/or energy value based upon the cost of providing the same service with expenditures of hardware and energy if the trees were absent (4). Lack of trees on sloping land requires compensating construction of water control

facilities. Around residences trees perform the same services as do house insulation, air conditioning, water and air purification and architechtural structures which control noise and create privacy. Most of these indirect benefits of trees are highly dependent upon the geometry of the trees in relation to the other components of the landscape.

These benefits of location, when combined with the advantage of minimizing distance between the crop production areas and sites of conversion and use, suggest that multi-use tree plantings will be most valuable when closely integrated into a community landscape which can efficiently utilize the products and benefits. The most striking success of this approach has been well demonstrated in China over the past several decades, where large-scale integrated tree-planting programs contribute to agricultural production and supply local material needs (5).

Solar Villages - Preparing for Sustainability

The concept of multiple crops and local uses runs against the common trend toward monocultures producing products for world markets. These trends, created by decades of cheap fuel, cheap fertilizer, cheap mechanization and cheap transportation, are destined to

change. Neither energy, nor fertilizer, nor machinery, nor transportation will be cheap in the foreseeable future. In addition, as soil erosion accelerates and toxins accumulate in air, soil and water, it is becoming clear that "conventional" practices of agriculture, pest control, water use and energy consumption are unsustainable. Economic forces will tend to favor local and regional, low-energy, fertilizer-conserving, less capitalized strategies (6,7,8).

As a response to these changes, attempts have begun to re-structure the ways in which human needs are met to make maximum use of solar energy and ecological principles that can sustain societies as fossil fuels decline. Recent advances in passive solar architecture intensive ecological agriculture, waste recycling and solar and wind technologies have established the feasibility of solar-based communities. Comprehensive landscape designs are beginning to be created which synthesize architecture, agriculture and technology into new combinations sometimes referred to as solar villages (9).

Trees play an important role in such designs:

i) Agriculturally producing human food and livestock feed in residential agricultural landscapes, polyculture orchards, and large-scale agricultural forests.

ii) Architecturally modifying residential climate by sun-shading, wind-control, noise reduction and evaporative cooling.

iii) Ecologically recycling waste nutrients back into useful products and services, filtering dust and waste gases.

iv) Materially producing firewood, timber and structural products for local use.

v) Aesthetically creating park-like green spaces where people can re-establish contact with other living things.

Few solar village or bioshelter designs have yet included community alcohol plants to convert local crops into liquid fuels. The usual strategy has been to minimize mobile transport, use petroleum efficiently when necessary, and reserve crops for local food and feed. These choices are due primarily to the unknown economics of the operating community-scale alcohol plants which exist. It is likely that alcohol plants would be integrated into solar village planning if:

i) the economics of conventional carbohydrate-conversion were favorable, or

ii) new techniques are developed for utilizing a wider range of feedstocks, particularly cellulosic materials.

In either case such a village alcohol plant could be operated somewhat as a public utility, collecting feedstocks from community plantings on public land and purchasing crops from individual growers in competition with other alternative uses.

Solar villages may turn out to be the most favorable sites for the testing of alcohol as a solar solution to liquid fuel production. For the same people who would opt for long-term sustainability of soils, waters, and forests by voluntarily limiting their consumption will understand the inherent security of self-produced self-contained fuel supplies. Tree planting depends upon people with long-term vision and upon an appreciation of the subtleties of long-term economics.

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THE ROLE OF MICROCLIMATE IN ENERGY USE EFFICIENCY[1]

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Introduction

The relationship between microclimate and energy use efficiency is a difficult one to generalize. In each situation different factors are of varying degrees of importance. The purpose of this report is to offer some general considerations concerning the relationship of shelterbelts and microclimate to energy use efficiency. By utilizing various characteristics of the microclimate of shelter a landowner may reduce the energy needed to grow crops, raise livestock, heat or cool the farmstead and maintain the farm working area.

Before we examine the benefits of shelter to these aspects of farm operation we must examine the physical changes in microclimate related to shelter from the wind.

Effects on Microclimate

The main effect of shelter is to reduce surface windspeed (Marshall 1967). Almost all other effects are secondary, a consequence of the reduction in windspeed. The effectiveness of a windbreak is dependent primarily on its height, density, width and length. Roughness of the ground surface and atmospheric stability also play a role in determining effectiveness. A dense windbreak will protect an area 10 to 15 times its height (H) downwind. By decreasing the density to 50 per cent the area protected downwind can be extended to 20 to 25 times its height. In either case the degree of protection is a function of the distance from the windbreak. As the density of a windbreak increases, turbulence in the lee of the windbreak is created due to the air overtopping the barrier. By increasing the porosity some wind penetrates the barrier and prevents the overtopping and turbulence (Marshall 1967, Rosenberg 1974, van Eimern et al. 1964).

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Air Temperature

Air temperature is a function of the amount of sensible heat transferred from the soil or plant surface to the air. The dissipation of this heat is influenced by turbulent mixing of the air. Reductions in turbulence will cause that parcel of air near a warm surface to become heated. Since the effect of shelter is a reduction in wind velocity and consequently a reduction in turbulent mixing, daytime air temperatures tend to increase in sheltered areas. However, night time temperatures tend to be cooler because of the formation of inversion layers in the sheltered zone (Rosenberg 1974). In general the degree of temperature variation is determined by windbreak permeability, soil moisture, cloudiness and net radiation. Windbreaks tend to increase the range of temperature within a 24 hour period.

Soil Temperature

The influence of shelter on soil temperature has been extensively reviewed by van Eimern et al. (1964) and others (Bates 1911, Caborn 1957, Rosenberg 1965). Bates (1911) suggested that the magnitude of increase in soil temperature was a function of many factors including depth, season, time of day, soil moisture, crop cover and others. Rosenberg et al. (1963) reported an increase in soil temperature of 1° to $2^{\circ}C$ under uniform crop conditions during both day and night.

Humidity

The literature on the influences of shelter on humidity must be viewed with caution. Not only do many of the reports deal only with relative humidity with no temperature considerations (Bates 1911, Caborn 1957, Rosenberg 1965) but many other factors are also ignored (van Eimern et al. 1964). In general, absolute humidity and relative humidity are greater in shelter, both by day and by night (Bagley & Gowen 1960, Rosenberg 1965, Rosenberg 1974).

Soil Moisture and Evapotranspiration

The effects of shelter on soil moisture are exceedingly complex (Caborn 1957). In general, two types of effects need to be considered: 1) the influence of the windbreak on the distribution of precipitation and 2) the influence of the windbreak on evaporation (Marshall 1967).

In areas where the majority of the annual precipitation occurs in the form of snow, the distribution of the snow is important. Windbreaks help control this distribution. The degree of distribution across a protected field is proportional to the height, width and density of the windbreak. The best distribution is obtained with permeable windbreaks somewhat open at ground level (Stoeckeler 1962).

Windbreaks also affect the distribution of rain due to the formation of a rain-shadow zone on the leeward side of the windbreak. The size

of this zone depends on the wind velocity and the height and density of the windbreak (Caborn 1957).

Dew formation may be increased in a narrow band 2-3H on the leeward side of a windbreak. The agricultural significance of dew may be limited even though some moisture may be absorbed through the leaf surface (Caborn 1957).

Besides influencing addition of moisture to the soil profile, windbreaks influence the removal of water by their influence on evaporation. Changes in windspeed, temperature and atmospheric gradients influence evaporative rates (Caborn 1957, Rosenberg 1974, van Eimern et al. 1964) and as a consequence atmospheric evaporative demand is decreased on the leeward side of a windbreak (Frank et al. 1974, Marshall 1967, van Eimern et al. 1964). Theoretically this should make more water available to plants for growth.

While the physical changes in microclimate due to shelter are fairly well established, the biological responses to these changes are less clearly defined.

Effect on Crop Production

Yields of wheat, rye, barley, oats and corn increased when protected by 40 year old cottonwood and boxelder windbreaks in North Dakota, South Dakota and Nebraska (Stoeckeler 1962). Shelter has also been shown to increase yields of forage crops such as alfalfa (Bates 1944, Trenk 1948), timothy (Trenk 1948), red clover (Trenk 1948) and crested wheat grass (Quayle 1941).

Increased yields of tomatoes and beans (Bagley 1964, Bagley & Gowen 1960), dry beans (Rosenberg et al. 1963) and soybeans (Frank et al. 1974) have been reported when protected by slat-fences. Radke et al. (1970, 1973) demonstrated increases in the yields of soybeans protected by temporary corn windbreaks. George (1971), however, indicated that in North Dakota yields of wheat were inconsistent and showed no significant differences when sheltered with slat fences. Likewise, Skidmore et al. (1974) found no consistent increases in wheat yields in Kansas.

In sugar beets the total weight of roots and beets increased in shelter of slat-fences but the top weight was unaffected and the sugar content of the beet actually decreased (Rosenberg 1966). During three different growing seasons, Brown and Rosenberg (1970, 1971) found that the benefits of annual windbreaks on the yields of sugar beets were much more pronounced during dry years than during years of adequate rainfall.

The inconsistency of these results has led other investigators to conclude that the amount of measurable benefit in crop yield is dependent on the severity of growing conditions (McMartin et al. 1974, Pelton 1967, Skidmore et al. 1974, van Eimern et al. 1964). In addition, the use of crop yield as an indicator of shelter-effects involves the sum of too many variables over too long a period to give consistent results. Changes in microclimate undoubtedly affect the development of the plant.

Therefore, the emphasis of research should be to determine how these small changes affect plant processes at various stages of development.

Winterkill and Wheat Yields

The effects of wind protection on winter wheat survival and yield in Eastern Nebraska have been observed periodically over the past 15 years. In many years weather conditions in Eastern Nebraska are such as to prevent extensive damage to the wheat crop due to winterkill. As a consequence, the value of wind protection in the production of winter wheat is often overlooked. However, in three of the last five years temperatures during October to February have averaged 4^{o} to $8^{o}F$ below normal. Table 1 illustrates the yields of winter wheat in sheltered and exposed areas and the temperature deviation from normal during each of these years (October to February). During the 1976-77 and 1978-79 growing seasons yields from sheltered plots were significantly greater than exposed plots. Yield increases were sufficient to more than compensate for the land lost to trees (Brandle 1980).

By increasing production on a smaller area the microclimate changes occurring as a result of shelter have increased our energy use efficiency, i.e. more grain produced per unit of fuel consumed.

Soybean Production in Shelter

Conflicting reports exist concerning the effects of shelter on soybean production and its relationship to plant water status (Frank et al. 1974, Radke et al. 1970, 1973). A recent study (Ogbuehi 1980) has shown that under rainfed conditions soybean yields increased 20 - 26 per cent as a consequence of an increase in water use efficiency. Furthermore, plants in shelter had higher CO_2 exchange rates and greater stomatal conductance at equivalent relative canopy heights in comparison to exposed plants. A study of the canopy structure indicates a greater leaf area development in shelter resulting in greater light interception. Longer internodes of sheltered soybean plants allowed greater spatial separation of leaves, lower canopy area density, deeper penetration of light to lower canopy strata and consequently greater utilization of available light.

Again modification of the microclimate has provided a greater energy use efficiency. In this case the benefit is not only greater grain production per unit fuel consumed but also more efficient use of available solar radiation.

Effects on Livestock Operations

The value of windbreaks for protection of cattle on range and pasture land is well established (Cross 1974, Zaylskie 1966). Livestock need protection from winter storms, especially in the Northern Plains States. Johnson (1947) estimated an average 33 per cent savings in winter feed requirements for stock with wind protection. Nebraska sandhills ranchers maintain that protective tree plantings greatly reduce livestock losses due to freezing temperatures, blizzards and the inaccessibility

Table 1. Comparison of annual yields of winter wheat, sheltered and exposed, with the deviation from the average monthly temperature (October - February).

	Yield (bu/A)		Temperature (^oF)
Year	Sheltered	Exposed	Deviation from Normal
1975-76	57.3	56.7	+ 3.30
1976-77	38.0	31.7	- 4.34
1977-78	*	*	- 6.68
1978-79	47.1	33.3	- 8.02
1979-80	46.6	43.8	- 0.38

* No yield data available

of feed (Cross 1974). The list of personal testimonies could go on at length.

While the value of windbreaks to ranchers and cattle producers is unquestioned, some scientists question their economic value in feedlot operations. Again personal testimony is overwhelmingly pro-windbreak. In Cuming County, Nebraska over 95 per cent of the feedlots are protected by over 2,065 acres of windbreaks (Cross 1974). Producers are convinced that cattle which are provided protection spend more time eating and less time bunched up for warmth. Protected cattle will gain more weight per unit of feed because less feed is required.

In contrast, Bond & Laster (1974) concluded that windbreaks provide little benefit "to winter growth or to feed efficiency of feedlot cattle in the Midwest". Their study showed conclusively that cattle provided with wind protection spent more time in protection than at the feed bunks and as a consequence gained less than those without protection.

At the University of Alberta a group of animal physiologists have been working extensively on the relationship between cold weather and energy requirements of cattle (Christopherson 1973, Christopherson & Thompson 1980, Young & Christopherson 1974, Webster 1970). Their findings indicate that the critical temperature (that temperature below which animals experience cold) of feedlot cattle is usually below an equivalent still-air temperature of -20^oF. They indicate that even in Canada long periods of -30^o to -20^oF are unusual. However, practical feedlot data indicate poorer feed efficiencies and consequently a reduced rate of weight gain during the winter months at temperatures

above the critical temperatures of the animals (Young & Christopherson 1974). They concluded that while generation of heat for body warmth may be required during stress periods it is not the major cause of an increase in feed requirements. The primary reduction in productivity results from physiological changes reducing digestion efficiency and arises from prolonged exposure to cold. Furthermore prolonged exposure to cold reduced apparent digestibility of dry matter 1.3 per cent units for each $10^{o}F$ drop in the average ambient temperature.

For example, a ration which has a dry matter digestibility of 70 per cent at $50^{o}F$ would offer 12 per cent less nutrients to the consuming animal at $-10^{o}F$ than at $50^{o}F$. Temperature fluctuations of this magnitude are relatively common throughout the Great Plains Region. Christopherson (1973) also showed that it is these abrupt changes in temperature which produce irregular feeding patterns in cattle and the resulting reduction in rate of weight gain.

The use of windbreaks to reduce windspeed alters the microclimate of the feedlot. As a result, ambient air temperatures are moderated and less feed is required for each unit of weight gain. Energy is conserved as a result of lower feed requirements as well as from reduced feed distribution demands. Again we have produced more of a given product while reducing our total energy usage, i.e. greater energy use efficiency via a modification of the microclimate.

Effects on Home Heating and Cooling

The value of windbreaks and other tree plantings in reducing home heating and cooling costs has only recently been revived. Recent investigations have illustrated the vast potential in energy savings of utilizing the microclimate changes due to shading and wind reduction.

Home Heat Exchange

Heat loss from a home occurs through three major processes: radiation transmission, heat conduction, and air infiltration (DeWalle & Farrand 1975).

The transmission of solar radiation through windows can be a valuable asset in winter and a significant liability during the summer. The amount of solar radiation penetrating a window can be controlled by judicious placement of trees. In addition, trees can also be used to influence the amount of solar radiation striking any surface of the building. Obviously it would be advantageous to maximize solar radiation during the heating season and minimize it during the cooling season.

The conduction of heat through solids is controlled by the thermal properties and thickness of the materials involved. Still air has one of the lowest rates of conductivity of materials found in the home. Thus, the value of insulation is related to the many small pores filled with air. Some materials such as glass have very high levels of conductance and therefore heat conductivity through windows is extremely

high. Heat conduction can account for 35-50 per cent of the total heat loss of a structure.

The best opportunities to control conduction losses are to reduce the temperature gradient across the barrier and to reduce the rate of heat movement through the barrier. The latter can be controlled relatively easily by insulation material but the temperature gradient itself is somewhat more difficult. Inner surface temperatures are largely controlled by the interior air temperature. Thus the gradient can be partially reduced by lowering the interior temperature. Outer surface temperatures are controlled by wind, air temperature and solar radiation. By reducing the wind velocity we can reduce the air turbulance and in turn enlarge the layer of still air next to the outer surface. In addition we have seen that a reduction in windspeed will also increase the air temperature in shelter due to a reduction in turbulent mixing. Again the judicious use of deciduous trees for shade will reduce surface temperatures in the summer and reduce cooling demands. During the winter solar radiation can be important in reducing heating demands by raising the outside surface temperature and reducing the temperature gradient. It should be apparent that these two processes can be conflicting and that a balance must be struck to maximize the utilization of the microclimate.

Heat loss by air infiltration is the process most directly affected by reductions in windspeed. Air infiltration is the movement of air through cracks, windows, doors or other openings. It is caused by pressure gradients between the inside and outside of a building. As wind velocity increases, the outer surface of a structure facing the wind will experience an increase in pressure and air will be forced into the building through available openings. On the leeward size of the building pressure is reduced and air moves from the building to the outside. Temperature gradients also contribute to this air movement. A severe combination of high wind and low temperature may cause the air in a home to be replaced as often as twice per hour. In most situations from 20-35 per cent of the heat lost by a building is lost by air infiltration (DeWalle and Farrand 1975).

Air infiltration through windows, doors and cracks can be reduced by diminishing the pressure of the wind by means of a windbreak. A study at Princeton University (Mattingly & Peters 1975) has indicated reductions in air infiltration rates as high as 60 per cent. The study was conducted with condominiums with common walls which tended to decrease the relative importance of the air infiltration factor and thus the importance of wind protection is underestimated.

Table 2 gives hypothetical data from four typical homes in Nebraska. Data were compiled from the AGNET system (Bodman et al. 1980) and values from the Princeton study were used to estimate expected reductions in air infiltration rates (Mattingly & Peters 1975). Three situations were considered: 1) No protection, 2) Protection by a single row of conifers - 40 per cent reduction in air infiltration and 3) Protection by a single row of conifers and a 7 foot high board fence - 60 per cent reduction in air infiltration. Potential savings of 13

Table 2. Effect of wind protection on the home heating costs and heat loss due to air infiltration of four Nebraska homes.

Degree of Protection	Infiltration Heat Loss BTU/HR	% of Total	Annual Heat Cost $/yr	% Saved
w/o protection	21325	33	325	---
w/tree windbreak	12795	23	283	13%
w/tree windbreak & 7 foot barrier	8530	16	261	20%
w/o protection	32730	41	537	---
w/tree windbreak	19638	29	448	16%
w/tree windbreak & 7 foot barrier	13092	22	404	25%
w/o protection	38827	65	335	---
w/tree windbreak	23296	53	248	26%
w/tree windbreak & 7 foot barrier	15530	43	203	39%
w/o protection	52152	74	393	---
w/tree windbreak	31291	63	279	29%
w/tree windbreak & 7 foot barrier	20860	53	220	44%

to 44 per cent were realized. In 1980 dollars these savings range from $64 to $173 per year.

Snow Management

Proper snow management by windbreaks is an integral part of any windbreak system. For field windbreaks the objective is to spread the snow evenly across the protected area and open deciduous species are most desirable.

For use with livestock operations the windbreak systems must be designed to prevent snow drifts in the feedlots and alleys. Poorly designed

systems may actually cause more harm than good. If snow is allowed to build up in the pens access to feed may be denied and the increased moisture may cause mud problems. In designing systems for feedlots care should be taken to provide enough room for snow deposition and proper drainage for melting snow.

In the protection of the farmstead itself care must be taken to prevent snow build up in drives, against doors or windows and in other work areas. In fact, shelter which is designed to protect the farmstead should take into consideration the working areas of the farmyard. Storage areas for machinery and equipment should be protected and the design of the windbreak should be such as to minimize snow removal efforts.

Windbreaks designed to protect farmsteads and feedlots are usually multiple row. There is normally a row of shrubs or low growing evergreens on the windward side with one or more rows of deciduous trees and one or more rows of tall coniferous species completing the windbreak. This will provide adequate snow stoppage as well as provide plenty of space for snow deposition. The amount of space needed for snow storage varies with geographic location and an adequate number of rows should be provided to provide sufficient storage.

One other aspect of snow management must be considered. Even though we have been primarily concerned with the individual farm situation we should consider the use of "living snow fences" for the protection of roadways. By proper placement and design the amount of snow removal necessary to provide access to the farmstead can be minimized and the resulting energy savings realized.

In summary by utilizing the various aspects of microclimate created by shelterbelts we can increase the amount product produced, reduce the amount of energy needed to perform various tasks and maximize the efficiency of the energy it is necessary to use.

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THE ROLE OF TREES IN A SUSTAINABLE GREAT PLAINS AGRICULTURE

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When we explore the role of tree crops for farm energy <u>co-production</u> rather than the potential of forest farming, we automatically give credit to diversified farming. This is important to us at The Land for we strongly believe the farm should be regarded more as a diversified hearth than as a food or energy factory. A different wording of the mission of this workshop might have invited a discussion of the prospect of tree farms, which would in turn generate visions of monocultures, large pulpwood processing factories and multimillion dollar investments by a few major corporate farming industries, including conglomerates.

In this era of the recognition of limits, it seems especially important for us to pay attention to asking the right questions. When we ask, "What is the role of trees in a sustainable Great Plains agriculture?", we are asking a value-laden question in which the key word is <u>sustainable</u>. We thank the organizers of this workshop for their sensitivity and care with the language, for most scientific and policy questions emphasize neither the importance of diversity and smallness nor the concept of sustainability, which is, of course, part of the problem of the times.

In approaching our assignment, there are certain assumptions we have made about the future, assumptions we believe in and assumptions which automatically tighten our range of speculation. By the year 2030, we expect that the public, for all practical purposes, will have made the following conclusions:

- fossil fuel is extracted, not produced;
- fossil fuel is to be treated as a transition fuel;
- nuclear power is finite and, even in the short run, is not a viable option due to many unresolvable uncertainities;
- fusion power will not be technologically practicable;
- renewable energy sources such as sun, wind and biomass conversion will have to meet most American energy needs in the forseeable future.

These assumptions point to a potentially heavy impact on the land. If we do have a society run on sunshine in 2030 that will accommodate all 300 million people, it will require direct harvest of the sun through millions of solar collectors, indirect harvest of the sun's rays through photovoltaic, through wind and hydro-electric and the growth and harvest of biomass to meet the need for heat and chemical energy demands. The exact personality of this oil-less future has not been comprehended and probably cannot be at this time. But we can say without any hesitation

that long before we arrive at this ecotopia, in our scramble to find the best crop mix, the temptation will be strong to scorch the face of the land. This will happen just to produce our own food and to meet a modest appetite for portable liquid fuels. To decide on the ratio of what we grow for food to what we grow for energy will likely be painful. Deciding on what is an energy need relative to what is a demand will be even worse.

Finding an Appropriate Standard

There must be dozens of agricultural mixes that are potentially sustainable for the Great Plains, dozens more that appear to be, but in fact would turn out otherwise. Most of the potentially sustainable mixtures of crops and livestock will probably hold no compelling promise, but a few of them, if tried, might surprise us and turn out to be outstanding candidates for a sustainable agriculture.

The problem quickly becomes one of finding a standard which will eliminate a lot of guess work. We have two standards, two sets of images, which we feel are most appropriate for this fossil fuel-less future. The most ancient standard has passed the time test. It has survived over the millenia. This standard is the native vegetation or vegetative structure which confronted the European settler, a landscape much different from what we see today. Old photographs and frontier writings tell us that the number of trees now present on the Great Plains is far greater than what the settler saw. At the eastern edge of the grasslands in Illinois and Indiana, in the tall grass prairie country, the decidious forest constantly threatened encroachment; and if the prairie had not been protected by fire, these woodlands would long since have marched westward, perhaps as much as 500 miles, experiencing little if any decline in species number along the way. Even with fire as the forest's main adversary, broadleaf woody vegetation managed to establish itself deep into the mid-grass prairie region and even to the land of the buffalo grass, but mostly in the protected, rich and moist stream bottoms. By the time it had reached this short grass prairie, however, one woody species after another of this gallery forest had dropped out until there were so few that serious encroachment to the adjacent hills was out of the question. With evaporation in excess of rainfall, burr oak, cottonwood and willow are about all that manage on a landscape in which few vertical structures can stand the wind and the winter.

We held this image, which was a reality in pre-settlement times, in our minds as we thought about our assignment, not so much because we were interested in pristine nature, but because we regarded it as our most prudent baseline for any consideration. It would be unreasonable to insist on this as the first and last standard to the exclusion of other considerations since pristine floras in at least a few other regions of the plant have been altered for human-directed purposes with no apparent reduction in sustainability.

It has been persuasively argued that the paucity of upland woody vegetation on the plains was the consequence of fires set either by lightning or Indians. Since fire no longer sweeps the vast expanses of prairie and probably won't again in the forseeable future, the woody flora which has already advanced considerably, may continue for a bit longer with no help from us. The pristine setting may be our most prudent, but not necessarily our best, model.

Our next most prudent consideration of the appropriate woody vs. herbaceous mix then would be the situation in the Great Plains after European settlement but before widespread fossil fuel use on farms. We have just mentioned two "wild cards" in this statement: culture and fossil fuel.

Northern Europeans and their descendents, with their cultures organized around humid-land mindsets, settled most of these grasslands. What if they had been settled from the Southwest instead of from the East, or what if most of the settlers had arrived from the Russian steppes or Kenya, or as conquering Indians from the Argentine? Culture is important. Remember the sod houses which were quickly abandoned when enough cash was acquired to buy lumber for wood frame construction? The European plowed the tall grass prairie and substituted the domestic tall grass, corn. He quickly moved west and plowed the mixed or mid-grass prairie and substituted the domestic mid-grass, wheat. Tragedy struck when he plowed the short grass and substituted wheat again. The dust bowl resulted. After twenty years and more, stubble mulching and other conservation techniques corrected much of the problem. But it is interesting that in the midst of the time of blowing dirt, the applied prescription or antidote for this ecological catastrophe, as part of national policy, was <u>trees</u>, mixtures of trees which became the famous shelter belts of the Great Plains. The shelter belt was the cultural product of the humid-land mindset, and its success was probably fortuituous. The young trees took root and thrived because the government's solution called for line plantings to stop the wind. And though it probably wasn't forseen, these line plantings became linear islands that took advantage of a surrounding "sea," which gave them a disproportionate supply of quality nutrients and winter moisture, both of which arrived by wind to settle in drifts and thus assure the success of one part of a New Deal. Cultural influence is definitely a "wild card," whatever the deal.

The second card, the influence of fossil fuel on the landscape, is just as "wild." It would be hard to measure the influence of fossil fuel on untended woody vegetation, but it probably amounts to little. The influence on human-planted materials, however, is another matter. Much less nursery stock would be maintained, distributed and nurtured without fossil fuel, for in most of this region the numbers of acres of established trees would have been miniscule without abundant water and human effort, both made possible by oil and gas energy.

Five Great Plains States: The People, Their Trees and Their Demands

The Great Plains is not the land of the tree. The dominating vegetative structure- grass -is well-adapted to the persistent horizontal force- wind. Even so, if there is one clear image the informed American has of the region, it is that our landscapes feature windbreaks and shelterbelts. A Currier and Ives type painting of a Kansas farmstead would likely depict the windbreak around the farmstead and feedlots, and the shelterbelt by the field. But those plantings would stand out because of the general paucity of a woody flora.

If we were to rope off the five principal states of the Great Plains, North and South Dakota, Nebraska, Kansas and Oklahoma, they would contain eight million people averaging thirty acres per person, or nearly 100 acres per household, with the entire population living in two and a half million homes. (Table 1)

TABLE 1. Five Great Plains States: Area, Population, Houses[1]

	North Dakota	South Dakota	Nebraska	Kansas	Oklahoma	Total
Area (10^6 acres)	44.3	48.6	48.9	52.3	44.0	238.1
State Population (10^6) July 1975	0.64	0.68	1.54	2.28	2.71	7.85
Owner-occupied Houses, Adjusted 1975 (1,000)	189.0	206.0	492.0	737.0	901.0	2,525.0

Per square mile, it is one of the least populated regions in the country, but as we will see, from a renewable energy standpoint, it could be one of the most overpopulated. Within these five state boundaries, a net annual woody biomass totaling somewhere between seventeen and 27 million tons is produced. (Table 2) The net annual merchantable growth, however, is less than three million tons.

Windbreaks, both the field variety and those which protect the farmstead and feedlot, account for less than a million acres of trees; less than half of one percent of the total five state acreage. (Table 3) Even so, there has historically been, and we should say there remains, a vigorous tree planting program. It was most vigorous from 1935 through 1942 during the Roosevelt shelterbelt program when 27.3 million trees were planted each year for a total of 218 million. Today the program is about half that, amounting to fifteen million a year on 61,000 acres. (Table 4)

TABLE 2. Net Annual Woody Yield Over Five Great Plains States

	North Dakota[2]	South Dakota[3]	Nebraska[4]	Kansas[5]	Oklahoma[6]	Total
Productive forest area (10^6 acres)	0.5	1.5	1.1	1.4	4.3	8.8*
Net Annual Biomass (10^6 tons)						
2 tons/acre- low	1.0	3.0	2.2	2.8	8.6	17.6
3 tons/acre- high	1.5	4.5	3.3	4.2	12.9	26.4
Net Annual Merchantable Growth (10^6 tons) @ 30 lbs/cu. ft.	0.15	0.46	0.21	0.21	1.75	2.78

*3.77% of States' Total Area

TABLE 3. Field and Farmstead Windbreaks[7]

	Windbreaks in 1000's Acres			As % of Productive Forest
	Farmstead Feedlot	Field*	Total	
North Dakota	117	608	725	145.0
South Dakota	3	4	7	0.5
Nebraska	114	66	180	16.0
Kansas	42	19	61	4.4
Oklahoma	2	6	8	0.2
TOTAL	278	703	981	11.0

* We assume 10 acres/mile

TABLE 4. Annual Tree Plantings over Five Great Plains States

STATE	Number of Trees Planted Annually[8] (in millions)	Number of Acres Planted Annually* (1000's)
North Dakota	8.0	32.0
South Dakota	3.2	12.8
Nebraska	2.0	8.0
Kansas	1.2	4.8
Oklahoma	0.8	3.2
TOTAL	15.2	60.8

* Assume 250 trees/acre.

TABLE 5. Supply and Demand for Wood and its Equivalent in Kansas

		Wood & Wood Equivalent in Millions of Tons
Supply		
Agricultural Residue[a] and Municipal Solid Waste[b]		3.3
Woody Biomass Production[c]		5.2
	TOTAL Supply	8.5
Demand		
Wood Products (no firewood)[d]		2.9
Fiber for Clothing & Home Furnishings[e]		0.2
Enthalpic Heat		
Residential[f]		13.9
Commercial[g]		7.4
Industrial[h]		29.0
Enthalpic Electricity		
Residential, Commercial & Industrial[i]		9.4
Transportation, Methyl Alcohol[j]		20.0
	TOTAL Demand	82.8
	Deficit	74.3

[a]The annual per capita energy value in agricultural residue for Kansas is calculated to be 12.6×10^6 BTU (Kansas Energy Office. 1979. Kansas Energy Profiles. p. 285, Dec. 1979. Topeka) At 8500 BTU/lb oven dry wood, this is equivalent to 0.74 tons of wood.

[b]There are 1.25 tons of municipal wastes generated per capita annually, with a heat content of 4500 BTU/lb (same reference as above). The annual per capita energy value then is 1.1×10^7 BTU. At 8500 BTU/lb oven dry wood, this is equivalent to 0.65 tons of wood.

[c]At 4 tons/acre net annual biomass, the 1.2×10^6 acres of eastern Kansas woodlands yield 4.8×10^6 tons of wood. At 2

tons/acre net annual biomass, the 0.2×10^6 acres of western Kansas woodlands yield 0.4×10^6 tons of wood. So Kansas woodlands have a net yield of 5.2×10^6 tons of wood.

[d]In 1979, the U.S. sawed lumber production was 36.6×10^9 board feet, which resulted from the removal of 14.0×10^9 cu. ft. of growing stock from U.S. forests (U.S.D.C. 1975. Statistical Abstracts of the U.S. p. 654) or a ratio of 2.61 bd. ft./cu. ft. removal. Based on this ratio, the 1978 U.S. production of 38.1×10^9 bd. ft. and net import of 10.0×10^9 bd. ft. (Bureau of Economic Analysis, U.S.D.C., 1980. Survey of Current Business. 60 (1):2-27) correspond respectively to the removal of 14.6×10^9 cu. ft. and 4.2×10^9 cu. ft. With the 1978 U.S. population being 218.5×10^6, the 1978 per capita removal of growing stock was 86.0 cu. ft., based on the present mix of hardwoods and softwoods in the U.S., assuming the average wood density of 29 lbs of oven-dry weight per cu. ft. of green volume. (Spurr, S. H. and H. J. Vaux. "Timber: Biological and Economic Potential." Science. 1976. 191(4227):753). So 86 cu. ft. has an oven-dry weight of 2,500 lbs or 1.25 tons per capita. Therefore, the Kansas population of $2.28 \times 10^6 \times 1.25$ tons gives us 2.85×10^6 tons.

[e]Wood fiber can be made into rayon and therefore we can calculate the rayon-equivalent potential of our wood products. In the U.S. now, we consume 80 lbs cotton equiv./person/yr., and this represents 75% of all fiber use. Therefore, 60 lbs cotton equiv./person x (1 lb rayon/1.5 cotton) = 40 lbs rayon-equiv./person. 95% transmission of fiber to fabric = 42.1 lbs rayon equiv./person. 100% conversion of alpha-cellulose to rayon yields 42.1 lb cellulose/person. There is a 30% conversion of wood to alpha-cellulose. Therefore, we would need 140 lbs of wood (0.07 tons) per person. Thus, (2.28×10^6 Kansas residents) (0.07 tons/person) = 0.160×10^6 tons.

[f]To determine enthalpic heat, one must total up the end-use energy in both direct fuel and electricity that is being used for heat. According to Amory Lovins, 75% of U.S. residential electric use is for heat (Soft Energy Paths. 1977. Friends of the Earth. San Francisco. Tables 4-3 and 4-4). Thus, for Kansas in 1977, the residential enthalpic heat use was 123.3×10^{12} BTU + (75%) (24.3×10^{12} BTU) = 141.5×10^{12} BTU. (Kansas Energy Office. 1979. Kansas Energy Profiles. Topeka. p. II-3.) At 8500 BTU/lb and 60% utilization efficiency, this requires 13.9×10^6 tons of wood.

[g]As in footnote f, the commercial enthalpic heat use for Kansas in 1977 is 65.8×10^{12} BTU. At 8500 BTU/lb and 60% utilization efficiency, this requires 7.4×10^6 tons.

[h]As in footnote f, the industrial enthalpic heat use for Kansas in 1977 is 294.7×10^{12} BTU = (6%) (21.0×10^{12} BTU) = 296×10^{12} BTU. At 8500 BTU/lb and 60% utilization efficiency, this requires 29×10^6 tons.

[i]The percent of the electricity consumed for bona fide electrical purposes in each of the residential, commercial, and industrial sectors in the U.S. was 25%, 60% and 94% respectively. (Lovins, Amory. 1977. Soft Energy Paths. Tables 4-3 and 4-4.) Thus the enthalpic electricity consumed in Kansas in 1977 = (25%) (24.3×10^{12} BTU) + (60%) (23.8×10^{12} BTU) + (94%) (21.0×10^{12} BTU) = 40.1×10^{12} BTU. Assuming a 25% efficiency of conversion of fuel wood energy into electricity (Pimentel, David et. al. 1978. "Biological Solar Energy Conversion and U. S. Energy Policy." Bioscience 28(6):379.) then 40.1×10^{12} BTU of electricity requires 1.60×10^{14} BTU of wood energy. At 8500 BTU/lb this amounts to 9.4×10^6 tons of wood.

[j]In 1977, the Kansas transportation sector consumed 272×10^{12} BTU. With a net energy balance of 13.6×10^6 BTU of methanol per ton of oven-dry wood, this requires 20×10^6 tons of wood. (See Reference 9 for the net energy balance for methanol on an acre basis.)

Supply and Demand for Wood and its Equivalent in Kansas

If we were to rope off Kansas and ask its 2, 280,000 citizens to save all their agricultural residue and municipal solid waste, and to harvest their net annual woody production to meet their current wood product and energy demands, they could meet only a tenth of them. (Table 5) This assumes today's level of conservation and no more passive and active solar homes than the state has today. Far and away the largest demand is for industrial enthalpic heat, requiring a third of the total. Eventually we could meet up to 42% of the industrial heat demand through solar preheating, with temperatures up to 350°F, and conservation would have to meet the other 58%. Residential and commercial enthalpic heat needs could be met with a combination of passive and active solar heat along with conservation. Kansas transportation would require about twenty million tons of wood as a source for methyl alcohol, about the same as the total for residential and commercial enthalpic heat demand.

Typical Kansas Farm Residence with Family of Four

The annual end-use, enthalpic energy demands in wood equivalent for the average farm residence, commercial and industrial excluded, amounts to 51.6 tons of wood equivalent. (Table 6) Nearly half this quantity

(24.5 tons) is for transportation and field operations alone. The next largest category is for residential heat, requiring a full third (18.9 tons of the total demand. The small supply value for agricultural residue and municipal sewage combined (5.6 tons) is so small because we are assuming that non-farm people will get their share of agricultural residue and municipal sewage. Thus, each Kansas farmer would have to grow on the average 51.6 - 5.6 = 46 tons of net harvestable woody biomass annually.

TABLE 6. Typical Kansas Farm Residence Raw Material and Energy Demand for a Family of Four[a]

		Tons of Wood Equivalent
Supply Entitled Family from "State Pool"		
Potential Agricultural Residue & Municipal Sewage		5.6
Demand		
Raw Materials		
Wood Products		6.0
Fiber for Clothing & Home Furnishings		0.3
Energy		
Enthalpic Residential Heat		18.9
Enthalpic Residential Electricity		1.9
Field Operations and Transportation[b]		
Methanol		24.5
	TOTAL	51.6
	DEFICIT	46.0

[a]This is based on end-use enthalpic energy demand and is expressed in wood equivalent. The commercial and industrial sectors are excluded. For references and calculations on the following, see footnotes in Table 5 with corresponding topics: Potential Agricultural Residue and Muncipal Sewage (see a & b), Wood Products (see d), Fiber-Clothing and Home Furnishings (see e), Enthalpic Residential Heat (see f), Enthalpic Residential Electric (see i).

[b]The energy used for field operations and transportation in agriculture for Kansas is 1.82×10^{13} BTU and 1.40×10^{13} BTU, respectively, which totals to 3.22×10^{13} BTU. (American Society of Agricultural Engineers, 1979. Energy Requirements for Agricultural Production in Kansas and Nebraska. ASAE Technical Paper 78-1518.) Since there are about 96,000 farms in Kansas (U.S. Dept. of Commerce. Bureau of the Census, 1971.

1969 Census of Agriculture, Counties, Kansas) the average fuel use per farm is 333×10^6 BTU. At 13.6×10^6 BTU of methanol/ton of oven-dry wood, the average farm needs 24.5 tons of wood annually to provide methanol for transportation use.

Supply and Demand for Wood and Its Equivalent in Five Great Plains States

If people in our five states harvest all their annual net forest production, save all their agricultural residue that is practicable and save all municipal wastes, they would have an equivalent of 28.5 to 37.3 million tons of wood. (Table 7) This sounds like a large number, but their demand would be around 250 million tons of wood or wood equivalent. The demand is nine times greater than the supply, and the 7.85 million people would experience a deficit of approximately 213 to 222 million tons of wood/wood equivalent. This amounts to a staggering deficit of approximately 28 tons/person.

The enthalpic heat and electricity for the commercial and industrial sector would require 60% of the total demand. The entire supply would not come close to meeting residential heat demands, and if turned into methanol, it would barely meet the transportation demands of the region's cars, busses and trucks.

The Future of Energy and Wood Production on the Land

Trees appear to be far better organisms for producing liquid fuels than cereals. (Table 8) Erosion will be less in a forest, and the total BTU yield could be 6.8 times greater with silviculture coppice (Table 8, column 4). Even with minimal management (Table 8, column 2), an acre of trees can out-yield an acre of 100 bushel corn three times over. These are positive considerations with trees, all on the supply side.

On the demand side, it is another story, and some of us promoters of regional semi-self sufficiency may find some of our conclusions disappointing. If we assume we should try to supply 210 million tons of wood to meet the energy, fiber and wood demands of 7.85 million citizens in the five states (Table 7), a massive tree planting will have to take place. Right now, 3.7% of the five state area is forest, about 8.8 million acres (Table 2). Of that total, less than a million acres was planted in one of the most expensive forestation programs ever. Even so, it accounted for a scant 11% of this region, which had a small forest area to begin with.

With this history in mind, let us consider some of the options available for meeting these demands, only a portion of which are outright needs. Ethanol from corn is not a viable alternative, even at 100 bushels an acre. We could plant corn in the entire five state area,

TABLE 7. Supply and Demand for Wood and its Equivalent in Five States.

		Wood or Wood Equivalent in Millions of Tons
Supply		
Net Forest Production[a]		17.6-26.4
Agricultural Residue[b] and Municipal Wastes[c]		10.9
	TOTAL Supply	28.5-37.3
Demand		
Raw Materials		
Wood Products[d]		9.8
Clothing & Home Furnishings (rayon equivalent)		0.6
Fuelwood		
Residential (Enthalpic heat)		47.7
Residential (Enthalpic Electricity)		4.8
Commercial & Industrial (Enthalpic Heat & Elec.)		150.9
Transportation (Cars, Buses, & Trucks Only)		
Methanol[9]		36.7
	TOTAL Demand	250.5
	Deficit	213.2-222.0

[a] Based on estimates of two and three tons per acre.

[b] The annual per capita energy value in agricultural residue for Kansas is calculated to be 12.6×10^6 BTU. Assuming this applies to the other four states, the total energy value for five states with a total population of 7.85×10^6 is 9.89×10^{13} BTU. At 8500 BTU/lb oven-dry wood, this is equivalent to 5.8×10^6 tons of wood.

[c] There are 1.25 tons of municipal wastes generated per capita annually, with a heat content of 4500 BTU/lb. The annual per capita energy value then is 1.1×10^7 BTU. With a five state population of 7.85×10^6, the annual energy value is 8.64×10^{13} BTU. At 8500 BTU/lb dry wood, this is equivalent to 5.1×10^6 tons of wood, assuming the other four states are similar to Kansas distribution in 1977. (Sources for b & c: Kansas Energy Office, 1979. Kansas Energy Profiles. p. 285.)

[d] This is for all annual wood products (no firewood) at the forest-level. In the five states are 7,850,000 people. If each used 1.25 tons of wood per person they would use 9,810,000 tons.

TABLE 8. Ethanol & Methanol Net Energy Balances Per Acre (in 10^6 BTU's)

	Ethanol	Methanol		
	100 bu. corn[a]	Tree Trunk 2.15 tons[b]	Trunk & Branch 2.67 tons[c]	Silviculture coppice @ 5 tons
Liquid Fuel Output	21.5	20.6	25.6	48
Farming + Harvest Input	- 18.4	- 6.0	- 7.4	- 14
Net	3.1	14.6	18.2	34
By-Product Credit	7.0	14.6	18.2	34
TOTAL	10.1	29.2	36.4	68
Millions of acres needed to supply 210 million tons Wood Equivalent	284	198	79	42
Millions of acres total for select states for comparison (from Table 1)	238.1 (all 5 Gt. Pl. States)	52.3 (Ks.) 48.9 (Ne.) 101.2	52.3 (Ks.)	44 (Ok.)

[a]Based on ethanol central plant. See Reference 10.

[b]Based on native North Dakota forest with biomass yield of 4.3 tons/acre @ 50% harvest. The number of wood tons can be multiplied by 13.6 x 10^6 BTU's to generate any of the totals under methanol. See Reference 9 & 12.

[c]Based on native North Dakota forest with 80% trunk and 50% branch harvest. Branches are estimated to make up 25% of above ground parts. Therefore, 50% plus ½ of 25% or 62% of 4.3 tons total yield = 2.67 tons/acre harvest.

and, under the unlikely optimum conditions necessary, which includes plenty of water for this arid land, we would need an additional area larger than the state of Oklahoma. (Table 8, column 1) Even so, corn can only provide energy, not wood or fiber. If we elect a much more passive approach, we can harvest logs from North Dakota-type forest conditions and nearly triple our energy efficiency in land use compared to corn. Such a system would require planting an area equal to Kansas and Nebraska combined. (Table 8, column 2) However, it would be wasteful not to harvest branches along with the logs. With the additional branch harvest we would reduce the total area significantly, requiring an additional forest area one and a half times as large as Kansas. (Table 8, column 3) Finally, if we were to get really enterprising and develop intensive silviculture coppices, then 42 million acres would be necessary, or an area a bit smaller than the state of Oklahoma. (Table 8, column 4)

To meet our current demands from trees, under the best of conditions discussed here, the current forest area would have to be multiplied 4.8 times; the total number of human-planted acres, 42 times. To promote any program of such scale without cautionary considerations would be imprudent. Here are some negative considerations.

- Trees would, in many cases, be in competition with food crops for the same acreage, and there would be even greater incentive to grow trees for energy than there now is for corn.
- Small patches of trees will draw moisture and nutrients from an area larger than they cover. Based on casual observations, this "hedgerow effect" could be 1.5 - 2 times the actual canopy area of the trees.
- Intensive coppicing will likely require, if not invite, the need for more water than the area could conveniently deliver and, probably in the long run, require more energy-intensive fertilizer.
- The impacts of methanol production plants on the environment due to chemicals could be significant and should be assessed early on.
- As we push for yield, there will be the same temptations to maximize yield, promoting genetic selection and a reduction of resistence. This will promote greater chemical dependency in pest control.

There are obvious benefits, including benefits to wildlife and, perhaps from the point of view of many, an overall aesthetic improvement of the landscape.

These considerations bring us back to the concern raised earlier in this paper, the problem of finding an appropriate standard against which to judge our actions. Our country has a long history of forcing the land to meet human expectations. One of the results of that attitude was the dust bowl. And though it may seem strange to our humid-land mindsets that a massive tree program on the Great Plains, yielding from three to almost seven times more BTU's/acre than 100 bushel/acre corn, could do any harm, we need to remind ourselves that

such a ratio of woody to herbaceous plants has not been part of the strategy of the sustainable ecosystem that greeted the white settlers. Perhaps we should find out why.

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Methanol Net Energy Balance[a]

INPUT		10^6 BTU/ton "Bone Dry Wood"
Farming		
Field tasks[b]		0.24
Petroleum[c]		1.28
Fertilizer[c]		.42
Machinery Manufacture[b]		.08
Seed Production[b]		.01
Harvest & Processing[d]		
Collect		0.2
Chip		0.5
Transport (ave. 40 mi.)		0.1
	TOTAL	2.8

OUTPUT

9.6×10^6 BTU/ton "Bone Dry Wood"

BALANCE

$9.6 \times 10^6 - 2.8 \times 10^6 = 6.8 \times 10^6$. However, the fuel gas credit is also 6.8×10^6 BTU's, yielding a total of 13.6 million BTU's.

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[a]This assumes no irrigation and is based on the Battelle process currently in the early stages of development.

[b]EPA, 1978. Preliminary Environmental Assessment of Biomass Conversion to Synthetic Fuels. EPA-600/7-78-204. Battelle Columbus Laboratories. p. 66. 5 tons/acre harvest assumed.

[c]Jenkins, D. M., T. A. McClure and T. S. Reddy, 1979. Net Energy Analysis of Alcohol Fuels. American Petroleum Institute Publication No. 4312. p. 8, 29.

[d]EPA. (Reference b above) p. 32.

PROVENANCE RESEARCH FOR TREE CROPS

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Establishment and culture of perennial woody plants should require less expenditure of energy than is needed for culture of most annual plants. If they can be harvested and utilized without high energy cost, trees and shrubs have the potential for being our most efficient solar collectors of the plant world. Our knowledge of their cultural methods and utilization is much more advanced than knowledge of their genetic characteristics. The potential for increased growth and fruitfulness by selection and breeding is great for many of these species due to their genetic diversity. Ecotypes adapted to specific sites have evolved by natural selection through many generations over thousands of years in response to the prevailing climates and soil types.

Provenance Testing

We can utilize these heritable differences among ecotypes and individuals of a species by selecting and breeding individuals possessing desirable growth, form, fruiting and pest resistance characteristics. A first step in the selection process is the determination of genetic and environmental components of observed variability among plants of different geographic origins through provenance testing. Provenance is another name for seed origin and refers to a group of plants growing under similar environmental conditions or in a certain locality. Provenance boundaries are definable initially only in very general terms, but can be refined when we discover significant genetic differences within the originally designated provenance.

All known climatic, topographic and other information concerning the natural range and genetic variability of a species is used as a basis for determining areas of sampling and in designing provenance test plantations. Biosystematic studies in the laboratory and greenhouse are helpful in providing information for selecting seed sources most likely to succeed in various test environments and for determining cultural procedures for the development of new genotypes or hybrids. This can be accomplished effectively by cooperative projects involving scientists located at several widespread stations. An example is the forest tree improvement project initiated in 1960 and involving eleven state agricultural experiment stations of the North Central Region of the U.S.

One generation of testing is often sufficient to identify improved seed sources. In fact, valuable information can be determined in less time by evaluating behavior and performance of young seedlings. However, if fruit is an important product, many additional years of observation will be required to determine potential yields. In order to speed up selections of superior genotypes, the most urgent research problem is to develop tissue culture techniques which would allow detection and recovery of superior genotypes from among gametic cells of selected trees (4).

A reliable supply of seed or plant propagules of the improved genotype must then be established for the using public. Plant patent or certification may be desirable to maintain purity of genotype or cultivar.

Crop Trees

Our conventional fruit and nut orchard crops are examples of progress made in woody plant improvement through selection during thousands of years of domestication. Refinements have been made through breeding and further selection over the past seventy years. Present and future energy needs dictate that we continue to develop these plants and investigate other woody plant species as sources of food and energy.

Hardwoods are generally considered better adapted for tree crops than are softwoods or conifers. Reasons for this include rapid juvenile growth; ease of mass production of selected clones; ability to sprout from stumps after harvest; and, in some instances, the possibility of producing an edible or usable fruit. Coniferous species, however, should not be discounted as components of energy plantations. Monterey pine (*Pinus radiata*), for example, is a very fast growing tree in Australia and New Zealand where it is being experimentally used in two-story cropping systems with grass and other agronomic crops. In this country jack pine (P. *banksiana*), another coniferous species, has rapid juvenile growth and wood which is desirable for pulp and paper production (15).

Tree Improvement Progress

Provenance testing and breeding have resulted in increased productivity of poplars (*Populus* sp.). Fast growth, ease of vegetative reproduction, and desirable products have encouraged research with these species. Although growth rates have been excellent for a few poplar hybrids, others have proved to be disease prone and short-lived (1,13). Significant gains in growth can be made by selection and subsequent breeding of individual eastern cottonwood (P. *deltoides*) trees (14). For example, the tallest trees in a Nebraska provenance plantation at age 14 were from Missouri, Nebraska and Ohio. Other differences among trees of the various provenances which may have significance are the larger leaves and the rougher and thicker bark of the trees of eastern origin as compared to those of the west.

Considerable genetic variability has been detected among sycamore trees (*Platanus occidentalis*), a fast growing species which sprouts vigorously

from young stumps (7). Sycamore wood is valuable as chips in making particle board and for pulp in the manufacture of various kinds of paper products in addition to fuel and other products.

Bey (5) found that black walnut trees (Juglans nigra) originating from localities 200 miles or more south of provenance test plantations in Illinois, Missouri, Indiana and Michigan were generally faster growing than trees from local or more northerly sources. Growth of northern trees in test plantations located in Minnesota and Iowa survived better and grew faster than trees of southern sources while trees of all provenances in the Kansas and Ohio test plantations grew about equally well. These tests indicated that tailoring genotype to location is as important with walnut trees as it is for corn and oats. Production and quality of fruit were not evaluated in this study. Over 400 black walnut cultivars have been named during the past 100 years based on fruit characteristics. Inadequate evaluation has resulted in the distribution of many popular but unproductive cultivars (8).

Persian walnut (J. regia) has been grown in eastern U.S. since the 1700's with only fair success (9). A concerted effort to find hardy and fruitful strains of this species adapted to southeastern Canada and eastern and central U.S. resulted in shipments of large quantities of seed from the eastern Carpathian Mountains during the 1920's and early 1930's. Selections have been made by amateur nut growers, but there has been no sustained organized program for improvement. A provenance study including origins from throughout the natural range of this species with test plantations strategically located in the north central and eastern U.S. would provide valuable information on genetic variability. This could result in Persian walnut becoming a successful crop tree in a large part of this country.

Pecans and hickories (Carya sp.) are valuable trees for wood and fruit. Cultivars of shagbark hickory (C. ovata) and shellbark hickory (C. laciniosa) have been selected by nut growers but few have been propagated because little is known of their relative value and they are difficult to transplant (11). Natural pecan-hickory hybrids have been discovered and named, but most have not been fruitful enough to be of value as nut producers. Pecan (C. illinoinsis) has been an important tree crop in the southern U.S. for over 100 years. Attempts to find cultivars which are fruitful in the central and northern regions of this country have met with little success (12). A research project designed to find hardy fruitful cultivars of pecan was established this year at the University of Nebraska by Dr. William Gustafson with financial assistance from the Northern Nut Growers Association. Cultivars included in this project represent a wide range of genetic variability and the study promises to add valuable information concerning their adaptation to the Central Great Plains Region.

Oaks (Quercus sp.) have received little attention from geneticists and plant breeders. The wood is valuable for many purposes and the fruit is a nutritious animal food. Unfortunately, relatively slow growth and difficulty of propagation has discouraged efforts in improvement research of oaks. Geographic variation of red oak (Q. rubra) has been

described by Kriebel, et al (10). Phenological and growth characteristics were evaluated, but a study of fruiting must wait until the plantations are twenty years or older. Rate of growth and acorn size of bur oak (Q. macrocarpa) was evaluated in a provenance test located in eastern Nebraska (6). Maximum growth was attained by sources originating about 100 miles south of the plantation. Bur oak native to and growing in the southern part of the natural range produces larger acorns than those of the northern sources in their native habitat. Size variance of fruits narrowed, however, in the Nebraska plantation indicating that environment, as well as heredity, was a significant factor in determining acorn size. Fruit yields of the various origins will be measured as the plantation becomes older.

Green ash (Fraxinus pennsylvanica) is being studied in provenance plantations by the University of Nebraska and The Pennsylvania State University. Since this species is native throughout the eastern U.S. and southern Canada and ranges from the high plains near the Rocky Mountains to the Atlantic Ocean, it can be expected to exhibit great genetic variability. It will sprout from stumps and is a potentially valuable energy source.

Hackberry (Celtis occidentalis) is another tree species with adaptation to a wide range of site conditions. A limited collection of seed sources from the Great Plains Region has verified large hereditary differences among individuals of this species (3).

Black locust (Robinia pseudoacacia) is a species of value as a soil builder and a source of naturally durable wood of high density. This latter characteristic will become more important as fossil fuels become more scarce. The small natural range of this species may reduce chances for great improvement through selection and breeding. The greatest problem which needs to be solved is the severe damage inflicted by the black locust borer.

Unique wood properties including great durability and high density makes osage orange (Maclura pomifera) a candidate for additional research. The unusual fruit may have much greater usefulness than repelling bugs from basements and serving as objects of decoration. Genotypic variation may be small due to its limited natural range. A thornless form has been discovered and propagated which may provide a basis for developing productive trees which are more safely harvested.

Honey locust (Gleditsia triacanthos) is a tree of wide adaptation and great apparent genetic variability. The objectionable bayonet-like thorns can be eliminated and the sex can be controlled by proper selection of cuttings. The wood is valuable as a source of energy and the fruit is highly nutritious and palatable to livestock. Except for the selection of ornamental varieties, little research has been done with this species since the quest for trees with pods high in sugar and low in bitterness by scientists of the Tennessee Valley Authority and a few eastern agricultural experiment stations in the late 1930's and early 1940's. Two of the sweetest cultivars discovered were named 'Millwood' and 'Calhoun'. Michigan State University has recently col-

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lected seed for a range wide provenance study. We have a limited collection of seedlings from several southern states in our nursery at the University of Nebraska which will be field planted in 1981. We also have two five-year old trees of the cultivar 'Calhoun'. They bore fruit at age three years but none since. Seedlings derived from open-pollination of 'Calhoun' have been field planted for observation and evaluation.

Another tree species, silver maple (Acer saacharinum) is fast growing and sprouts vigorously from stumps up to one foot in diameter. Genetic variability of trees of this species is a subject of research at the University of Nebraska.

Other tree species of potential value as sources of energy are Scotch, Austrian, ponderosa and jack pine. These are all currently subjects of provenance research in Nebraska and the other states of the North Central Region. A Scotch pine clonal seed orchard has been established at the University of Nebraska Field Laboratory near Mead under the direction of Dr. David Van Haverbeke of the U.S. Forest Service. Evaluation of its progeny is now underway. This orchard will be a source of seedlings in the near future for tree planters of Nebraska and the surrounding states.

Conclusions

The tree species mentioned in this paper are among those which could be integrated into the agriculture of the central Great Plains Region of this country. Development of productive cultivars would provide the basis for them to become an important crop for both dryland and irrigated farms in multi-purpose plantations. Shelterbelts for cropland protection can be designed for trees within the belts to be harvested on a rotation basis. Fruit could also be collected from these plantations. Those trees which produce useful and usable fruit could also be part of a two-story farming system in which trees and low-growing conventional crop plants occupy essentially the same area (2).

We may discover that a system involving trees as partners with other plants could increase net energy production by agriculture if we implement imaginative research and development programs in all phases of agroforestry.

Abstract

Provenance testing provides information for selection and breeding of tree and shrub species for increased growth and fruitfulness. Potential for success is greatest for those plants which grow naturally over a large geographic area. Improvement of growth or fruitfulness has been realized for Populus species, black and Persian walnut, pecan and several pine and other coniferous species but much more research is needed with all woody species including those which have been domesticated for thousands of years.

PLANT TISSUE CULTURE AS AN AID IN DEVELOPING NEW TREE CROPS WITH MULTIPLE USES

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ABSTRACT

Techniques of culturing cells, tissues, and organs aseptically can help in the development of multi-usage tree crops. They can be employed to establish pathogen-free stocks and to collect, preserve and transport germplasm. They can be the principal method of propagation. Some techniques might be tried in hybridization and variety development.

INTRODUCTION

The term "plant tissue culture" denotes, collectively, cultures of isolated cells, tissues and organs. The cultures share the basic features of asepsis, i.e., freedom from microbial infestation and artificially provided nutrients and environment. Plant tissue culture began 80 years ago with Haberlandt's attempt to cultivate mesophyll cells. Today, it is used extensively in research and is rapidly gaining prominence as a commercial practice. Objects of the more intensive investigations are morphogenesis, somatic cell genetics, plant-microbe interactions, diverse metabolic phenomena, and membrane transport processes. The major horticultural applications are establishment of pathogen-free stocks and rapid clonal propagation. In addition to the long-practiced embryo culture, plant breeders now have limited use of ovule and ovularly cultures to circumvent incompatibility problems, cell cultures to screen mutants, androgenetic haploids to hasten hybridization and mutation breeding, and protoplasts to create novel hybrids.

This communication describes briefly the state of the art and some ways in which the use of tissue culture could hasten the development of new, multi-purpose tree crops.

PATHOGEN EXCLUSION AND GERMPLASM PRESERVATION AND EXCHANGE

One of the earliest horticultural application of tissue culture was the recovery of virus-free plants from infected clones. Inasmuch as trees are perennials, there is ample time for their contracting all kinds of diseases. Lacking effective control measures, the germplasm contained in diseased trees could be lost permanently. Trees used as crops are usually propagated asexually and, should infection especially by viruses and virus-like pathogens set in, repeated propagation by traditional vegetative methods can lead to all plants of the clone becoming infected. Germplasm extinction can nevertheless be avoided, and yield and quality losses can be regained by restoring the pathogen-free state. One or another tissue culture technique can help with the restoration.

Pathogens usually are not distributed throughout the diseased plant and uninvaded tissues can be found. Pathogen-free plants can be recovered by isolating and

culturing such tissues. This principle has been applied successfully to a multitude of crops (24, 26). To illustrate, Table 1 lists viruses and related pathogens that have been excluded from citrus cultivars by application of an *in vitro* technique.

With trees, the best method of obtaining pathogen-excluded plants is the grafting of 0.1- to 0.3-mm tall stem tips from infected sources onto seedlings or other miniature rootstocks that are known to be pathogen-free (29). All manipulations must be performed aseptically and development of grafted plants allowed to occur *in vitro* until transplantable size is attained.

Tissue cultures are also receiving increasing acceptance for international exchange of plant germplasm (16, 35, 48). There is virtually no risk of spreading insects, mites, nematodes, and other pests. Also, adherance to rigid protocols enables exclusion of most pathogens.

Excised stem tips of the dimensions used in virus elimination are cryopreservable (41). Indeed, freeze-storage of cultured or culturable organs and cells should be considered very seriously as an alternative for long-term preservation and collection of tree germplasm, particularly when seeds are unavailable or when clones must be maintained.

RAPID CLONAL PROPAGATION

Trees are extremely heterozygous, so their seeds are unreliable as propagules for the establishment of uniformly productive stands. Trees selected for production purposes must be reproduced vegetatively. If there is no urgency to attain extensive plantings, traditional asexual methods, such as graftage, will suffice. However, if vast plantations must be established quickly, a substantially faster method of plant multiplication must be found.

The past 10 years have seen the emergence of tissue culture as a major propagation method of numerous crops, including flowers and other ornamentals, vegetables, field crops, fruits, and forest trees (25, 26). We recently compiled published reports of over 350 species that are reproducible asexually *in vitro*. Those of tree species that have some relevance to multi-usage crops are listed in Table 2. Depending on the plant regeneration method employed, different multiplication rates are obtainable. But even the slowest of tissue cultures yields plants at rates several thousand times faster than any traditional method.

Clonal propagation by tissue culture might also be used to improve variety screening. Traditionally, progeny tests have depended on observations of single plants to identify superior genotypes. There has been little opportunity or effort to compare the multitude of genotypes in ecologically varied situations. Tissue culture can help in eliminating the deficiency. Any number of plants of each genotype is reproducible very easily and quickly and, thus, larger samples can be used to evaluate its performance in one or many potential cropping sites.

In spite of the expected advantages, tissue culturing should not be attempted without an awareness of the possibility of encountering discouraging obstacles. Successful plant regeneration among tree species has remained confined to tissues of juvenile plants or organs. Until research breakthrough enables plant regeneration from adult tissues, it may be imperative that the tree contains

pools of juvenile cells that can be tapped for explants. Frequently, juvenile outgrowths can be obseved in some adult trees, e.g., in Sequoia and Eucalyptus. In several instances, severe pruning has been used to force juvenile outgrowths (9). Phase reversal has also been achieved in a few plants through graftage (7), application of hormonal substances (36) and other manipulations (10).

Being perennials, seasonal growth fluctuations should be expected of trees. Plant regeneration and other developmental processes are subject to control by periodically recurring climatic changes. For example, temperate and tropical trees manifest varying degrees of dormancy during winter, and desert natives are quiescent in summer. Fulfillment of a tree's seasonal needs, for example of photo- and thermoperiods, may be prerequisite to its successful propagation by tissue culture.

Outdoor plants are usually heavily laden with dust, spores and other potential sources of tissue culture infections. The trees to be propagated may need to be grown in a greenhouse to minimize disinfestation problems.

The release of self-intoxicating substances has hindered the use of tissue culture with some species. There is no universally effective method of preventing the release. But detoxification has been achieved in some cases by adding adsorbents, e.g., activated charcoal, and antioxidants, e.g., ascorbic and citric acids, to culture media.

Clonal propagation, whether by traditional methods or tissue culture, may fail to reproduce exact copies of a cultivar, giving rise instead to some genetic or epigenetic variants. Polyploid plants are frequently generated by tissue culture. Whereas polyploids are sometimes desirable, the priority of clonal propagation is to reproduce the original plant. The plagiotropic habit of lateral branches, an epigenetic trait of many trees, is transmissible through tissue culture. Thorniness, lateness in maturing and other negative characteristics may be encountered when propagation is restricted to explants of juvenile tissues. Variability is cultivar dependent. It is accentuated when plants are regenerated through an adventitious process. And repeated subculturing can further magnify the incidence of anomalous plants.

AIDS IN ATTAINING DESIRED VARIETIES

Tissue culture techniques can be used to circumvent many obstacles to plant breeding and to extend a crop's germplasm pool. For over 50 years, embryo culture has been used to rescue normally unattainable hybrids. The extreme case is evident in the orchids, where embryo culture has contributed to hybrids involving combined genomes of five and more genera. A recent survey revealed successful embryo cultures of more than 40 families of plants (26). The technique has been employed in two distinct situations. In one, the preponderance of cases, embryo culture has been used simply to achieve aseptic germination of the fully differentiated but undersized embryos contained in mature seeds. An agar solution of salts, sugar and one or more vitamins has sufficed for germination. The other situation has involved relatively undifferentiated embryos excised from immature ovules. Their successful rearing has required supplementation with endosperm preparations, high sugar levels, osmotica, or balanced mixtures of hormonal substances.

Should seed development fail before the hybrid embryo reaches culturable dimensions, rescue is still possible by culturing the whole ovule. The media of embryo cultures have also been satisfactory for ovule cultures.

Ovules and ovularies might be excised prior to pollination and subjected to "test-tube fertilization," to overcome certain incompatibility barriers. The pollen can be applied directly onto ovules in vitro (31) or injected as a suspension into ovularies before their placement in nutrient medium (21).

Cultures of immature anthers or pollen could yield haploid trees. By starting with isogenic plants, the time needed to develop hybrids and varieties can be shortened considerably (14, 27). The detection of mutants is also simplified with haploid plants or cells. Two approaches have been used to obtain androgenetic plants. In one, embryos are allowed to develop directly from pollen by culturing anthers in a relatively unsupplemented medium. In the other approach, anthers or pollen are first placed in a medium enriched with callus-forming substances. The callus is subsequently transferred to another medium in which the hormonal balance has been altered to favor embryo initiation or shoot differentiation. The probability of generating haploid plants is better with the first approach. The callus intermediary method is sometimes the only recourse, but is usually associated with a mixture of haploid, diploid and polyploid plants.

Single cells and protoplasts might be dispersed into nutrient agar and challenged with pathogen toxins, herbicides, metabolic analogs, high salts, extreme temperatures, and other appropriate agents and screened for potentially beneficial variants. Plants regenerated from the variants can be incorporated into the breeding program or cloned and used immediately as new cultivars. Table 3 lists examples of cultivar improvements gained with variants from cultured cells or protoplasts.

The extent of its germplasm diversity sets the limit to which a crop can be improved genetically. Occasionally, a desired trait can be obtained by mutagenesis. More often the needed traits exist among relatives, hybridization with which is not possible through conventional breeding methods. Perhaps the genes could be transferred to the tree crop by protoplast fusion. Indeed, fusion of somatic cell protoplasts has resulted in otherwise unattainable hybrids between Lycopersicon and Solanum (23), Atropa and Datura (17), Arabidopsis and Brassica (12), and Aegopodium and Daucus (8). Note that the successful hybrids were from fusions between family members only. The many reports of interfamilial hybrids, even between plants and animals, by cell fusion cannot be taken very seriously at this time. It is inconceivable that the barrier to genetic union is eliminated by simply removing the cell wall. The protoplast is a cell without the rigid wall, the latter having been hydrolyzed by enzyme treatment in hypertonic medium. Polyethyleneglycol is widely used to aid fusion of protoplasts.

Tree breeders can also anticipate the day when they will be using protoplasts and cultured cells to achieve genetic transformations. Plasmids, viruses, organelles, and synthetic lipid vesicles are being investigated as possible carriers for the introduction of foreign genes into plant cells.

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Table 1. Viruses and virus-like pathogens excluded from citrus cultivars by shoot-apex grafts performed in vitro.

Disease	Pathogen	% Pathogen-free plants obtained	Reference
Stubborn	Spiroplasma	100	39
Dweet Mottle	Virus	7	38
Infectious Variegation	Virus	100	39
Psorosis A	Virus	0-100	39
Psorosis B	Virus	100	38
Seedling Yellows-Tristeza	Viruses	75-100	38, 39
Tristeza	Virus	100	39
Vein Enation	Virus	100	38
Yellow Vein	Virus	80	39
Excortis	Viroid	78-100	38, 39

Table 2. Tree species with relevance to multi-usage potential and regenerated asexually in vitro.

Plant Species	Explant	Plant Regeneration Process	Reference
Acacia koa A. Gray	Stem tip	Adventitious shoots	44
Aegle marmelos L.	Hypocotyl	Adventitious shoots, embryos	2
Castanea sativa Mill.	Lateral bud	Axillary shoots	46
Citrus spp.	Stem, root, nucellus	Adventitious shoots, embryos	6,13,33,34
Coffee arabica L.	Leaf	Adventitious embryos	25
Coffea canephora Pierre ex. Froehn.	Stem	Adventitious embryos	28
Corylus avellana L.	Embryo	Adventitious embryos	47
Diospyros kaki L. f.	Hypocotyl	Adventitious shoots	49
Gleditsia triacanthos L.	Cotyledon	Adventitious shoots	37
Malus domestica Borkh.	Stem tip	Axillary shoots	18
Malus sylvestris Mill.	Stem tip	Adventitious and axillary shoots	1
Prunus spp.	Stem tip, leaf cotyledon	Adventitious and axillary shoots	4,15,22, 19,40,43
Theobroma cacao L.	Embryo	Adventitious embryos	32

Table 3. Examples of cultivar improvements enabled by variants isolated from cells or protoplasts cultured in vitro.

Crop	Improved Trait	Reference
Tobacco	Resistance against wild fire (Bacterial disease)	5
Corn	Resistance against Southern blight (Fungal disease)	11
Potato	Resistance against early & late blights (Fungal diseases)	42
Sugarcane	Resistance against eye spot (Fungal disease)	30
Sugarcane	Reistance against powdery mildew (Fungal disease)	30
Sugarcane	Resistance against Fiji disease (Viral disease)	30
Tobacco	Resistance against IPC herbicide	3
Sugarcane	Drought tolerance	30
Sugarcane	Increased temperature tolerance	30
Sugarcane	Increased sugar yield	20

UTILIZATION OF MESQUITE AND HONEY LOCUST PODS AS FEEDSTOCKS FOR ENERGY PRODUCTION

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ABSTRACT

The direct fermentative production of ethanol from agricultural residues, such as corn stover, has previously been examined with a mixed culture of Clostridium thermocellum and Clostridium thermosaccharolyticum at MIT. Using this mixed culture concept, the carbohydrate rich pods from hybrid mesquite (Prosopis alba X Prosopis velutina) and honey locust (Gleditsia triacanthos) represent potentially useful substrates for liquid fuel production.

Examination of these substrates shows a 43.5% and 25.8% α-glucoside content for hybrid mesquite and honey locust, respectively. However, these substrates have also been shown to contain 22.5 and 24.3% additional carbohydrate in the form of α-cellulose and pentosan.

Hybrid mesquite was shown to be a readily fermentable substrate for the production of ethanol by mixed and mono cultures. Up to 83% of the total carbohydrates present in hybrid mesquite were utilized with the production of ethanol at 80% of theoretical yield.

INTRODUCTION

Sucrose rich pods and beans from honey locust and mesquite represent renewable tree crops. Although sucrose is an important substrate for traditionally fermentatively derived ethanol production, it is not the only carbohydrate available in these pods. It is therefore important to assess the significance of other fermentables such as cellulose and hemicellulose in these substrates as well as to examine the extent to which they can be used for the production of ethanol.

Clostridium thermosaccharolyticum is an obligate anaerobic thermophile. This organism has a wide range of sugar utilization which includes many hexoses and pentoses common to natural biomass (1). In addition, the organism possesses α-glucosidase, amylase, xylanase, and pectinase activities. Although wild strains of this organism can ferment these substrates to alcohol, large quantities of organic acids such as acetate,

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lactate, and butyrate are also produced. Mutation and selection for ethanol tolerant and overproducing strains have resulted in isolates such as HG-4 and HG-6 which produce ethanol in higher yields (2). However, C. thermosaccharolyticum cannot ferment cellulose. In order to utilize this component, a second thermophilic anaerobe, Clostridium thermocellum, can be included in mixed culture. This organism cannot ferment pentoses but excretes a complement of enzymes with celluase as well as xylanase activities. These enzymes have been shown to hydrolyze substrates such as solka floc and corn stover to a mixture of glucose, cellobiose, xylose and xylobiose (3). Strains of this organism such as S-4 and S-7 have also been selected which tolerate and produce ethanol in higher yields (4). The use of this mixed culture has previously been examined for the direct production of ethanol from cellulosic substrates such as solka floc and corn stover (5). However, seeking alternate feedstocks for the production of liquid fuel, the translation of this process to sugar containing substrates such as mesquite and honey locust appears to be quite appropriate. In theory, the advantage of using this mixed microbial system being the higher ethanol yield attainable since the cellulosic, hemicellulosic, and sugar fractions in the pods can be utilized.

MATERIALS AND METHODS

Mesquite beans from both a wild type and hybrid type (Prosopis alba X Posopis velutina) were provided by R. Inman* from SERI, Golden, CO. Honey locust pods (Gleditsia triacanthos) were supplied by G. Williams of the Int. Tree Crop Inst. The pods and beans were stored frozen at -32°C upon receipt. The samples were then dried for 4 hrs at 50°C in a Proctor and Schwartz forced air dryer. Analysis of the biomass and fermentation studies were performed using oven dry samples milled with a Wiley rotary knife mill with a 2 mm screen. Pentosans were determined by destructive distillation to furfural according to the A.O.A.C. pentosan method (6). The α-cellulose content of the pods, defined as the fraction remaining insoluble in 24% KOH at 25°C, was determined as "holocellulose" prepared according to the method of Wise et al. (7). Lignin was analyzed by the T13 TAPPI standard method developed at Wisconsin (8), and crude protein was determined by microkjeldahl procedure (9). The α-glucoside and starch content of these substrates were evaluated enzymatically. Substrates (10 g/l) were autoclaved (15 min 120°C) with 20 mM phosphate buffer (pH 6.9) and 6 mM NaCl. Type I α-glucosidase (Sigma) at 0.8 U/ml and tetracycline (200 μg/ml) were added and incubated at 37°C. Reducing sugar production was monitored by dinitrosalicylate method (10). When equilibrium was achieved, type II-A α-amylase (Sigma) was added at 2.2 mg/ml and the incubation was continued at 30°C until equilibrium was again reached.

Batch fermentations of these substrates were examined in monoculture with a high ethanol yielding strain of Clostridium thermosaccharolyticum HG-6-62 isolated and reported previously (11). Fermentation of mesquite and honey locust (50 g/l) were conducted in anaerobic flasks with CM-4 medium as previously described (4). After media sterilization (15 min, 120°C), inoculation was accomplished with a 5% exponentially grow-

*Supplied to SERI by P. Felker of the University of California at Riverside

ing culture of HG-6-62 and incubated at 60°C. NaOH (5 N) was periodically added to maintain the pH at 6.5. Mixed culture fed batch fermentations were performed in an 8 l New Brunswick fermentor in which 50 g/l of hybrid mesquite and CM-4 medium were sterilized (20 min, 120°C). A 5% inoculation of HG-6-62 was added at time zero and additional hybrid mesquite (sterilized as a 50% w/w aqueous slurry) was sterilely added periodically to maintain the residual sucrose level between 3 and 18 g/l. After 42 hours of fermentation, an additional 5% inoculation of Clostridium thermocellum S-7 was added. Ethanol, acetate and lactate end products were assayed by gas-liquid-chromatography and enzymatically as described previously (5).

RESULTS AND DISCUSSION

The compositions of wild type and hybrid mesquite, as well as honey locust, are summarized in Table 1. The major component and fermentable carbohydrate, sucrose, has been reported to make up 24% of honey locust pods (12), and between 27 and 32% of various varieties of mesquite beans (13). Although virtually no free reducing sugars are detectable by DNS assay, honey locust and wild type mesquite demonstrated 25.8% and 31.8% reducing sugar liberation, respectively, after α-glucosidase treatment. These results are in substantial agreement with previous findings.

Table 1
Composition of Honey Locust, Wild Type, and Hybrid Mesquite

	Honey Locust	Wild Type Mesquite	Hybrid Mesquite
α-glucosides (sucrose)	25.8	31.8	43.5
pentosan	9.9	14.6	9.5
α-cellulose	12.6	11.2	14.8
lignin	8.1	7.5	10.8
protein	16.6	11.4	10.4
ash	3.8	5.8	6.0
lipids (ether extractables)	3.2	3.2	3.5
% Closure	80.0	85.5	98.5
% Fermentable Carbohydrate	48.3	57.6	67.8

Hybrid mesquite, however, was shown to contain a significantly higher "sucrose" content of 43.5% as determined through enzyme treatment. The addition of α-amylase to these samples resulted in little further increase in reducing sugar indicating the absence of significant quantities of starch. In addition to sucrose, a significant pentosan content between 10 and 15% and α-cellulose content between 11 and 15% were also found in each substrate. Besides carbohydrates, analyzing the lignins,

protein, ash, and lipid contents, we were able to account for 98.5% of the hybrid mesquite. However, only 85.5% of the wild type mesquite and 80% of honey locust could be accounted for. A total "sugars content" of 56%, however, has been reported for honey locust.[12] This higher sugar level may represent the balance of the substrate unidentified. Nevertheless, the carbohydrates assayed for represent 48.3% of honey locust, 57.6% of wild type mesquite and 67.8% of hybrid mesquite on the basis of 50°C oven dry weight (approximately 88% of air dry weight).

The ability of C. thermosaccharolyticum HG-6-62 to ferment the α-glucoside and pentose sugars to ethanol was examined during batch fermentation of these three substrates. The fermentation of 50 g/l honey locust by HG-6-62 is shown in Figure 1.

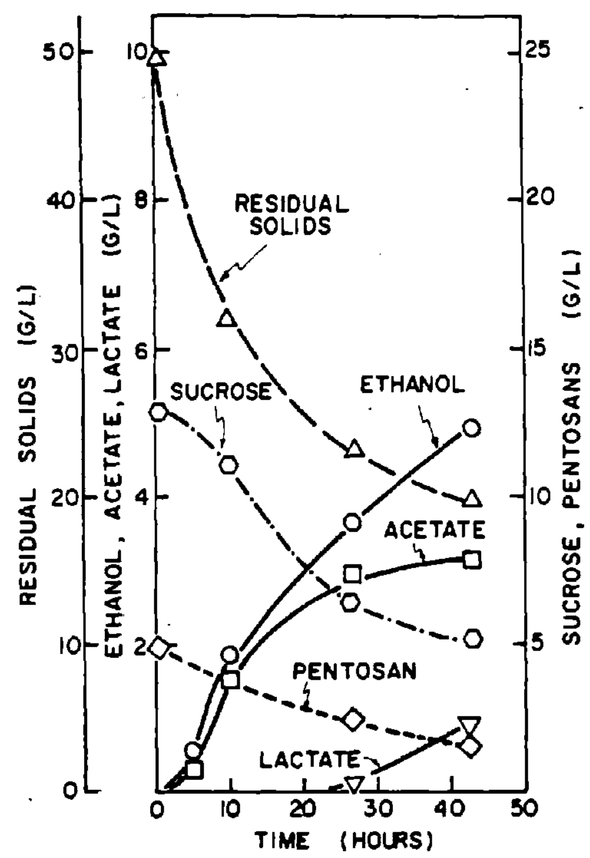

Figure 1. Batch Fermentation of Honey Locust (50 g/l) by C. thermosaccharolyticum HG-6-62

This monoculture resulted in the production of 4.9 g/l ethanol, 3.1 g/l acetate and 0.9 g/l lactate after 42 hours of fermentation. Although 30.3 g/l of residual solids were found to have been utilized during

fermentation, a total of only 11.1 g/l pentosans and 7.1 g/l sucrose were consumed. After 42 hrs of fermentation, a calculated yield of 0.1 g ethanol per gram substrate fed and a maximum ethanol productivity of 0.13 g/l-hr were obtained.

A low ethanol yield and productivity, as well as a concomittant slow rate of sucrose utilization, were consistently observed in repeated monoculture fermentation of honey locust by HG-6-62. This behavior may be the result of an inhibitory component in honey locust. In view of this result, further work with honey locust was discontinued.

In contrast, however, the batch fermentation of wild type mesquite with C. thermosaccharolyticum, HG-6-62, shown in Figure 2, resulted in the rapid and complete utilization of sucrose and 80% utilization of pentosan found in this substrate after 40 hours. In this case, a higher ethanol productivity of 0.22 g/l hr was achieved although the ethanol yield was only 0.08 g/g substrate fed.

The fermentation of hybrid mesquite by C. thermosaccharolyticum HG-6-62, shown in Figure 3, demonstrates both dramatically higher ethanol

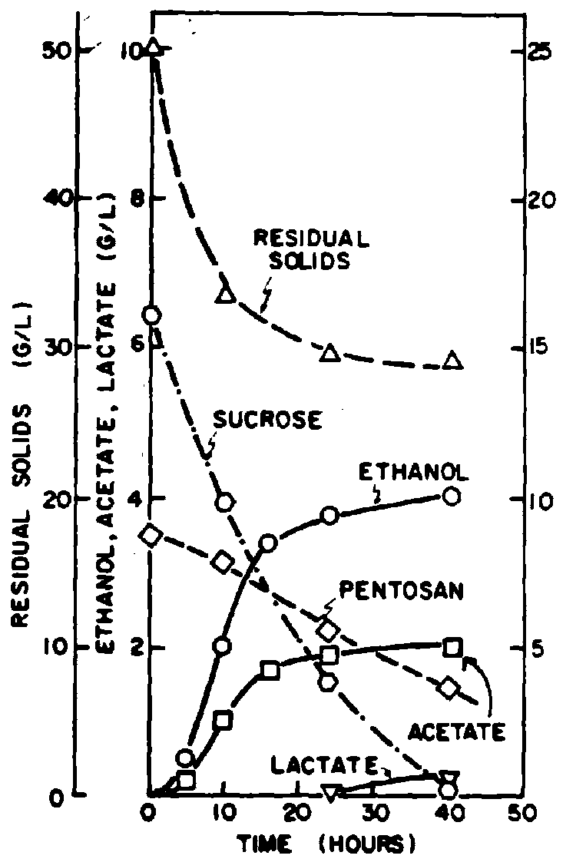

Figure 2. Batch Fermentation of Wild Type Mesquite (50 g/l) by C. thermosaccharolyticum HG-6-62.

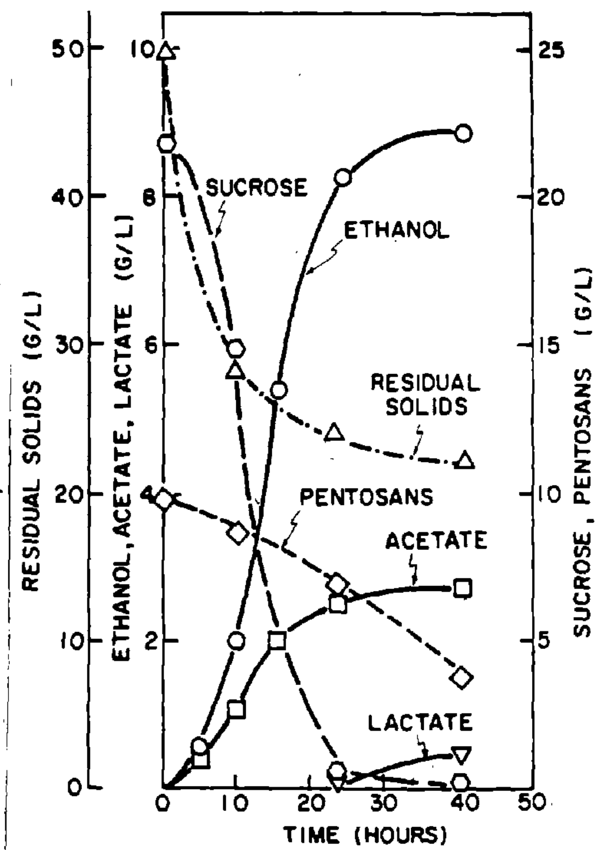

Figure 3. Batch Fermentation of Hybrid Mesquite (50 g/l) by C. thermosaccharolyticum HG-6-62.

yields and higher volumetric productivities. After 25 hours of fermentation, the bulk of the sucrose was consumed producing over 8 g/l ethanol and 2.5 g/l acetate. After 40 hours of fermentation, 63% of the pentosans were consumed as well. This rapidly fermented substrate produced 0.18 g ethanol per gram substrate fed with a maximum volumetric productivity of 0.33 g/l hr. On the basis of fermentable carbohydrate actually consumed, an ethanol yield of 0.40 gram of ethanol per gram of substrate consumed was calculated which represents 80% of the maximum theoretical yield attainable. The data from the fermentations summarized in Table 2 demonstrates that hybrid mesquite is the best substrate of those examined for ethanol production with this organism.

Table 2
Monoculture Fermentation of Honey Locust and Mesquite by Clostridium thermosaccharolyticum Strain HG-6-62

	Honey Locust	Wild Type Mesquite	Hybrid Mesquite
Maximum Ethanol Productivity (g ethanol/l-hr)	0.13	0.22	0.33
Ethanol Yield (g ethanol/g substrate consumed)	0.16	0.19	0.40

However, when using a monoculture fermentation it is not possible to degrade the α-cellulose which makes up over 20% of the available carbohydrate in this substrate. The addition of the cellulolytic C. thermocellum S-7 should effect the hydrolysis of this fraction thus leading to the further production of ethanol.

Therefore, a mixed culture fermentation was performed using the hybrid mesquite. The microorganisms used for this mixed culture fermentation were Clostridium thermosaccharolyticum strain (HG-6-62) and Clostridium thermocellum strain (S-7).

In order to achieve a maximum level of ethanol, this fermentation was conducted in a fed batch manner. This was necessary to provide sufficient carbon source to attain a high ethanol concentration without introducing substrate inhibition. As in previous monoculture fermentations, HG-6-62 was inoculated first. However, additional hybrid mesquite, up to a total of 126 g/l was sterilely fed to maintain the residual sucrose concentration between 3 and 18 g/l. After 42 hours of fermentation, C. thermocellum S-7 was then inoculated. The kinetic profile of this fermentation is shown in Figure 4. After 60 hours of fermentation, 55 g/l sucrose, representing 100 g/l of total mesquite fed, had been consumed by the mixed culture. After 80 hours of fermentation,

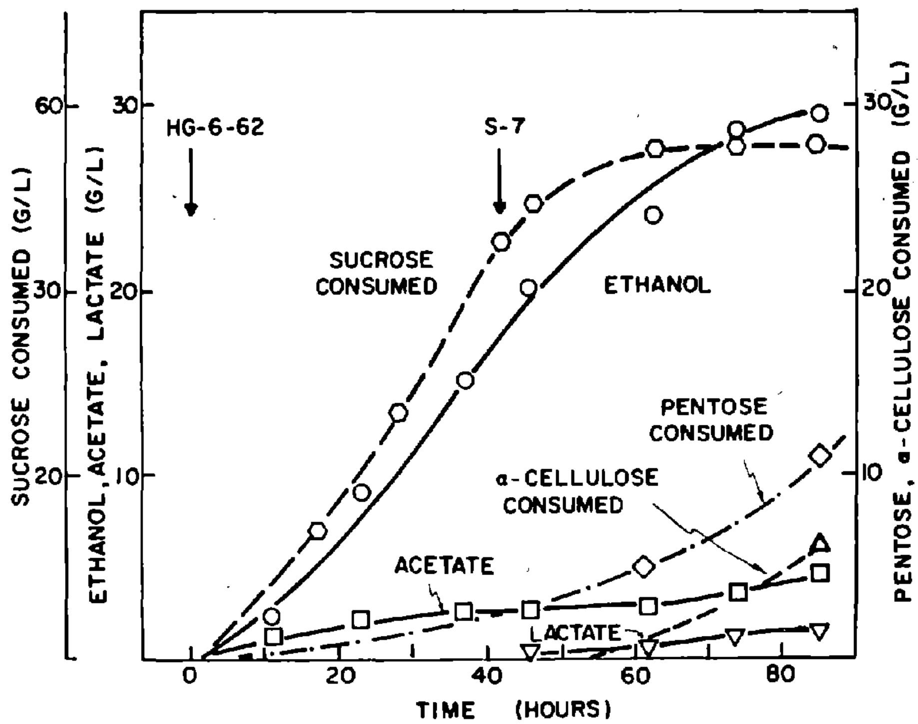

Figure 4. Mixed Culture Fed Batch Fermentation of Hybrid Mesquite (126 g/l) by C. thermosaccharolyticum HG-6-62 and C. thermocellum S-7

pentosan and α-cellulose determination of the residual solids showed that 11 g/l pentosan and 6 g/l α-cellulose were consumed. Thus, 90% of the pentosan and 32% of the α-cellulose fed had been converted into products. The mixed culture produced 30 g/l ethanol, 4.5 g/l acetate and 1.4 g/l lactate. The production of 3.8 vol % ethanol was achieved with a maximum ethanol productivity of 0.44 g/l and at 80% of the theoretical yield based on substrate consumed (Table 3). On a comparative basis (see Table 3), the use of mixed versus monoculture resulted in a 28% increased yield from 0.18 to 0.23 gram of ethanol per gram of hybrid mesquite fermentated. It should be pointed out, however, that if the residual α-cellulose is continually degraded by S-7, a maximum theoretical yield of 0.27 g ethanol/gm mesquite fed could be potentially achieved. Finally, it does not appear that the 3.8 vol % ethanol produced was a limiting factor as these organisms have been shown to achieve 50% of maximum growth at concentrations approaching 5 vol %

Table 3
Mono and Mixed Culture Fermentation of Hybrid Mesquite

	Batch Monoculture HG-6-62	Fed Batch Mixed Culture HG-6-62 and S-7
Maximum Ethanol Productivity (g ethanol/l-hr)	0.33	0.44
Ethanol Yield (g ethanol/g substrate consumed)	0.40	0.40
Ethanol Yield (g ethanol/g substrate fed)	0.18	0.23

of ethanol (5). However, attaining solids concentrations greater than 126 g/l does represent a significant limitation to the operation of conventional stirred tank reactor which was employed.

CONCLUSION

In summary, preliminary compositional analysis of pods and beans from honey locust and two types of mesquite have been performed. Up to 67.8% of hybrid mesquite is potentially utilizable for ethanol production. In addition to sucrose, a significant quantity of pentosan and α-cellulose making up 36 to 47% of the total fermentable carbohydrates has been identified. The best substrate of those examined both with respect to carbohydrate content and ethanol yield from fermentation has proven to be hybrid mesquite. Through the use of a mixed culture of thermophilic anaerobic Clostridia selected for high ethanol yield, at least 83% of these carbohydrates can be consumed with the production of ethanol in 80% of theoretical maximum yield.

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Session III

Discussion and Recommendations
Chairman — Robert Inman
Biomass Program Office, SERI

"What might not happen if every wild, crop-bearing tree was improved to its maximum efficiency?"

". . . a vast work is proposed. It is nothing less than the deliberate creation of a whole new set of crop trees and then to make a new agriculture based upon the use of these new crop trees." "It could employ the full time of a man, of ten men, of a hundred men, of five hundred men. After it really got underway, it might employ as many men as it takes to man and operate a battleship. Oh, for a battleship! That is to say the money required to build, maintain, and operate one."

J. Russell Smith

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DISCUSSION AND RECOMMENDATIONS

Chairman - Robert Inman
Biomass Program Office, SERI

During the final morning session of the Workshop, a spirited examination of research, development, and demonstration needs ensued along the direction outlined below. The discussion was guided by the responses received from a questionnaire circulated during the first two days of the Workshop (see Appendix B). In addition to the direct questions posed, various participants addressed the issues of sustainable agriculture, scale of applications, and monocultures versus polycultures.

It is difficult to accurately assess the potential of tree crops or agroforestry technology as an integrated component of modern farming because such technology is generally not practiced. Of the many approaches and potential applications discussed at the workshop, only shelterbelt technology is practiced commercially, though not with tree crops. Shelterbelt science has advanced to a point where shelterbelts can be planted for designated conditions and applications. Other systems which were discussed, such as mesquite or honey locust pod production for fermentation to ethanol or Chinese tallow seeds for waxes and oils, have but recently attracted research attention. Of still other proffered systems only fragmentary and possibly misleading information is available. No quantitative estimation of the "quad potential" of agroforestry, therefore, is possible at this time.

The Conferees were unanimous in the opinion that research on selected aspects of agroforestry is needed. There was general agreement that either the U.S. Department of Energy or the U.S. Department of Agriculture (or both) should take responsibility for supporting a structured research program. The Conferees' estimates for the annual budget required for research and development averaged about $2,500,000, but there was a wide range of estimates. At that level, most agreed that substantial application of agroforestry technology would occur by 1995.

The most pressing research priorities which the participants identified fell into three general categories: resources, processes, and applications. Perhaps due to the background of the Conferees, resource related priorities were mentioned most often. Selection and evaluation of species and crop management programs based on appropriate energy use in integrated farming systems were judged in most need of research support. With a few exceptions, high yield claims for tree crop products aired during the Workshop were based on data obtained from only a few trees. Though these yields are the best information available, they are certainly suspect and must be substantiated on a reasonable scale. Other research concerns centered about questions of harvesting, germplasm, environmental and

social effects, regional studies, propagation, marginal land use, and economics.

Under the processes category, most of the comments reflected research needs in crop product conversion technology, ethanol and chemical yields, by-product identification, cellulose conversion, and small-scale processing equipment. While much interest was voiced in fermentation studies, ethanol potential from tree crops was controversial due largely to its dependance upon economical yields of substrates and the lack of convenient harvesting methods. Many participants emphasized the need to consider conversion processes or potential uses other than ethanol production. On the other hand, mesquite pods have been shown to be a highly suitable fermentation substrate and honey locust pods can also be fermented. It is entirely possible that these species or others with similar characteristics could be developed separately as "alcohol crops".

Discussion of the third category, applications, brought up the need for farm-scale system analyses including energy analyses, multiple-purpose usage of land and total tree utilization, uses for by-products of conversion products and identification of new applications.

One point that the questionnaire addressed specifically was possible negative aspects or insurmountable problems that the tree crop concept might incur. Although no insurmountable negative aspects were identified, a number of potential problem areas were discussed. Technical problems were not emphasized since many were already mentioned before, but rather, social and economic issues were addressed. These included resistance to change on the part of the farm community, lack of research funding and commercial financing, unfavorable cash flow due to long lead times before trees bear crops, potential long-term environmental problems (though the prospect of putting marginal land into tree crop rather than row crop production would be very desirable), danger of overselling the prospects, and problems dealing with government agencies.

In spite of the potential problems, many participants were eager to initiate demonstration-scale planting of the most promising currently identified species in order to examine the yield questions. The feeling was that this should be done soon due to the time lag problem.

An effective approach for such a research program would be the concept of interplanting tree crops with conventional field crops or pasture. Within this approach, shelterbelt science could be relied upon to provide needed focus to identify and develop suitable applications. Conventional shelterbelt compositions and configurations could be modified, leading either to concentrated or dispersed plantings that yield energy, wood, harvestable tree crop products, livestock shelter, soil protection, or farmstead energy conservation, while also enhancing conventional crop yields.

Some difficulty is anticipated in convincing the funding agencies that a tree crop or agroforestry research program is necessary. Compared with today's sophisticated and hardware-oriented approach to energy technology development, on-farm agroforestry might appear anachronistic to those responsible for directing the nation's energy programs. Such a perception would ignore the benefits that the small farmer, and agriculture in general, could reap from but a modest, properly focused program. Launching a tree-crop program will therefore first require visibility for the concept, and later detailing the benefits that could be derived. To accomplish the first task, the Conferees have recommended a series of regional workshops to further consolidate and publicize existing interests in agroforestry and to identify appropriate farm energy benefits. A structured program could then be devised and coordinated with existing biomass programs, building initially upon proven and familiar practices such as shelterbelt technology. Once the program was underway, it could be expanded to include other innovative systems.

Afterword

Until such time that a significant National Program is implemented to explore the many facets of the co-production of energy from tree crops, we at SERI will help keep interest alive through a series of proposed actions:

- o The tree crop task force will continue as a focus of ideas, planning, and communication at SERI.
- o A systems study of the use of tree crops for ethanol or other chemicals will be undertaken, focusing on farm applications. (D. Hertzmark).
- o Efforts will be made to co-sponsor a series of regional workshops to focus on regional species and applications and to expose a broader audience to the concepts addressed in this workshop. (Task force and regional sponsors)
- o Chemical analyses and fermentation studies of tree crops will be continued at SERI as part of the Chemical and Biological Division's broader program related to unconventional crops for fuels and chemicals. (R. Villet - Biotechnology Branch)

From the enthusiasm expressed by participants at the meeting, it may be safely assumed that most will also continue their already very substantial interest and activities as the potential for this energy/agricultural concept unfolds.

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APPENDICES

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APPENDIX A

The following bibliography contains general references obtained from a computerized literature search. These references are provided as a supplement to the many crop-specific citations included with the papers. The relative paucity of citations from the computer search undoubtedly results from the ambiguous usage of descriptors to catalogue articles dealing with "tree crops".

Agroforestry and Forest Farms

- a Bibliography -

20 October 1980

prepared for

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PREFACE

This bibliography is a compilation of a variety of journal articles, books, proceedings of papers presented and others, all of which deal with the subject of agroforestry and farm forestry. It is the result of a literature search conducted primarily through the computerized DIALOG Information Retrieval Service. A variety of data bases in DIALOG were searched, but nearly all of the citations reported here were retrieved from Agricola and Commonwealth Agricultural Bureaux Abstracts.

This bibliography is intended as a general introduction to the subject. The search was based on identifying and retrieving citations where forestry and agriculture were combined. By design, no specific crop product, crop plant, crop culture, or geographic area was used to focus (bias) the search.

The bibliography which follows contains 115 citations from all over the world. Citations have been arranged alphabetically by the primary author's last names. Following the bibliography are two indexes where citations are cross-referenced:

- by crop type or culture; and
- by the vegetation zone.

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Zaman, M.B. and H. Rashid. 1977. Black pepper-a cash crop for agroforestry in Bangladesh. Bano Biggyan Patrika. Vol. 6, No. 1. pp. 33-35.

Citations Cross-Referenced by Type of Crop

The citations have been sorted by the type of crops or crop products described in either the article's title or key words or descriptors from the data base. Sorting was done according to five categories:

- o one plant/two or more raw materials (e.g. leaves for forage and wood for fuel);
- o one plant/one raw material/two or more products (e.g. wood as a source of extracted chemicals and fuel);
- o a forest crop and an herbaceous forage crop;
- o a forest crop and a row crop; and
- o a forest crop and an orchard crop.

A sixth category was made for including citations for which no crop was specified in title, key words or descriptors. If a citation could be classified according to more than one category, it was. For brevity only the primary author's last name and date of publication are referenced here.

(1) One Plant/Two or More Raw Materials

Anderson,	1977	Foster,	1979	Pak,	1977
______,	1976	Greenstock,	1978	Pendleton,	1976
Aroksaar,	1978	Hunt,	1979	Randhawa,	1977
Brewbaker,	1976	Kargaard,	1976	Samingan,	1972
Callaghan,	1974	MacDaniels,	1979	Schettini,	1974
Christisen,	1978	Malcolm,	1977	Soedjono,	1978
Donev,	1976	Male,	1976		
Farnsworth,	1977	Maydell,	1978a		

(2) One Plant/One Raw Material/Two or More Products

Nikiforov, 1975

(3) Forest Crop and Herbaceous Forage Crop

Adams,	1976	Dickson,	1978	Knowles,	1975b
Aguirre,	1977	Douglas,	1973	Loucks,	1977
Anderson,	1979	Farnsworth,	1976	McQueen,	1976a
______,	1967	Farnsworth,	1977	McQueen,	1976b
______,	1978	Guerrero,	1975a	Olsen,	1974
Barr,	1973	Guerrero,	1975b	Randahawa,	1977
Bishop,	1978	King,	1976	Thomas,	1978
Cook,	1977	Knowles,	1972	Tustin,	1975
Dearborn,	1976a	Knowles,	1975a	Wu,	1976
Dearborn,	1976b				

(4) Forest Crop and Row Crop

Anderson,	1979	Denamany,	1979	Singh,	1975
Arokssar,	1978	Erven,	1979	Yu,	1971
Bene,	1977	Kim,	1979		

(5) Forest Crop and Orchard Crop

Christisen,	1978	Jaynes,	1969	Randahawa,	1977
Foster,	1979	Jaynes,	1979	Thompson,	1976
Gramada,	1972	Payne,	1979	Zaman,	1977
Hershey,	1947	Pusung,	1977		

(6) Others Not Classified

______,	1973	Holmstrom,	1974	Monyo,	1976
______,	1979	Holmstrom,	1975	Munk,	1969
Araneta,	1978	Huguet,	1978	Olawoye,	1975
Bergmann,	1974	Igbozurike,	1978	Ordinario,	1978
Brookman-Amissah,	1976	Imp.Ag.B.,	1947	Phillips,	1968
Cumberland,	1976	Jaciw,	1979	Roche,	1973
Cunningham,	1978	James,	1974	Samapuddhi,	1975
Davies,	1979	King,	1979	Smith,	1975
Donis,	1975	Kio,	1972	Smith,	1976
Douglas,	1976	Knowles,	1973	Spedding,	1975
Duckham,	1970	Kuo,	1977	Spurgeon,	1979
Elliot,	1967	Lipinsky,	1978	Steinlin,	1978
Enabor,	1974	Lowe,	1974	Stewart,	1978
Farnsworth,	1975a	Lundgren,	1975	Strand,	1976
Farnsworth,	1975b	Matthews,	1973	Sulpa,	1978
Farnsworth,	1979	Maxwell,	1979	Tixier,	1977
Generalo,	1978a	Maydell,	1979b	Troughton,	1976
Generalo,	1978b	Maydell,	1978c	Tustin,	1979
Graham,	1941	Maydell,	1978d	Vergara,	1976
Hall,	1972	McKelvey,	1975	Wamugunda,	1973
Hershey,	1936	McQueen,	1979	Wilken,	1977
Hershey,	1940	Mollison,	1978		

Citations Cross-Referenced by Vegetation Zone

The citations have been sorted by the vegetation zone representing the location of the subject of the article. Information in the title, keywords or descriptors was used to identify the vegetation zone directly, the geographic location of the subject, or, as a last resort, the location of the authors/organization originating the article. Twelve vegetation zones were used as described by H. Walter*. A thirteenth category includes articles which could be classified only as "tropical", and the fourteenth category includes articles not otherwise classified. If a citation could be classified according to more than one category, it was.

(1) Evergreen, Rain Forests of the Lowlands and Mountain-Sides (cloud forests)

Aroksaar,	1978	Guerrero,	1975b	Roche,	1973
Bishop,	1978	Kio,	1972	Samapuddhi,	1975
Brookman-Amissah,	1976	Olawoye,	1975	Samingan,	1972
Denamany,	1979	Ordinario,	1978	Soedjono,	1978
Guerrero,	1975a	Pusung,	1977	Zaman,	1977

(2) 2. Semievergreen and Deciduous Tropical and Subtropical Forests

Brewbaker,	1976	Lundgren,	1975	Roche,	1973
Cook,	1977	Maydell,	1978c	Samapuddhi,	1975
Enabor,	1974	Maydell,	1978d	Wamugunda,	1973
Kio,	1972	Olawoye,	1975		
Lowe,	1974	Randhawa,	1977		

(3) 2a. Dry Woodlands, Natural Savannas or Grassland (tropical and subtropical)

Anderson,	1979	Hall,	1972	Wamugunda,	1973
______,	1978	Lundgren,	1975		
Dickson,	1978	Monyo,	1976		

(4) 3. Hot Semideserts and Deserts Polewards up to Latitude 35°

______,	1976	Kargaard,	1976	Pak,	1977

* H. Walter. 1973. Vegetation of the Earth. Heidelberg Science Library. Vol. 15. Springer-Verlag. New York.

(5) 4. Sclerophyllous Woodlands with Winter Rain

None

(6) 5. Moist Warm Temperate Woodlands

Aguirre,	1977	Farnsworth,	1979	McQueen,	1976a
Barr,	1973	King,	1976	McQueen	1976b
Cumberland,	1976	Knowles,	1972	McQueen,	1979
Davies,	1979	Knowles,	1973	Strand,	1976
Dearborn,	1976a	Knowles,	1975a	Troughton,	1976
Dearborn,	1976b	Knowles,	1975b	Tustin,	1975
Farnsworth,	1975a	Kuo,	1977	Tustin,	1979
Farnsworth,	1975b	Malcolm,	1977	Wu,	1976
Farnsworth,	1976	Male,	1976		
Farnsworth,	1977	McKelvey,	1975		

(7) 6. Deciduous (Nemoral) Forests

______,	1967	Gramada,	1972	Matthews,	1973
Bergmann,	1974	Hershey,	1936	Maxwell,	1979
Callaghan,	1974	Hershey,	1940	Munk,	1969
Christisen,	1978	Hershey,	1947	Payne,	1979
Cunningham,	1978	James,	1974	Smith,	1976
Donev,	1976	Jaynes,	1969	Stewart,	1978
Erven,	1979	Jaynes,	1979	Thompson,	1976
Elliot,	1969	Kim,	1979	Wilken,	1977
Foster,	1979	Loucks,	1977	Yu,	1971

(8) 7. Steppes of the Temperate Zone

None

(9) 7a. Semideserts and Deserts with Cold Winters

None

(10) 8. Boreal Coniferous Zone

Andersnn,	1977	Holmstrom,	1975	Hunt,	1979
Holmstrom,	1974	Huguet,	1978	Jaciw,	1977

(11) 9. Tundra

None

(12) 10. Mountains

None

(13) Articles Classified only as "Tropical"

_____,	1979	Maydell,	1978a	Steinlin,	1978
Araneta,	1978	Maydell,	1978b	Thomas,	1978
Bene,	1977	Phillips,	1968	Vergara,	1976

(14) Articles Not Classified

Adams,	1976	Greenstock,	1978	Pendleton,	1976
_____,	1973	Igbozurike,	1978	Singh,	1975
Donis,	1975	Imp.Ag.B.,	1947	Smith,	1953
Douglas,	1973	King,	1979	Schettini,	1974
Douglas,	1976	Lipinsky,	1978	Spedding,	1975
Duckham,	1970	MacDaniels,	1979	Spurgeon,	1979
Generalao,	1978a	Mollison,	1978	Sulpa,	1978
Generalao,	1978b	Nikiforov,	1975	Tixier,	1977
Graham,	1941	Olsen,	1974		

APPENDIX B

Questionnaire used at the workshop to guide the discussion during Session III.

QUESTIONNAIRE

Tree Crops for Energy Co-Production on Farms

Respondent's Name____

1. Should there be a concerted Research, Development and Demonstration Program in Annual Tree Crops for Energy?

	Yes	No
Research & Development	_____	_____
Demonstration	_____	_____

2. Please list specific research, development and demonstration opportunities that would deserve a high priority in such a program?

3. What public and/or private agencies/institutions should administer such programs?

4. Total Annual Budget?

5. By what date would these efforts result in substantial applications being implemented?

6. What negative aspects or insurmountable problems do you perceive in this concept? (Social, economic, environmental, technical)

7. Other remarks:

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APPENDIX C

Current list of participants addresses.

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Tree Crops for Energy Co-Production on Farms

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